Study into the feasibility and design of a renewable energy portfolio for the Klein Constantia Wine Estate

Derek Andrew Cecil Leisegang

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Declaration:

I hereby declare that the following is my own unaided work, both in conception and execution, and that apart from the normal guidance of my supervisor; I have received no added assistance in its completion. I also declare that I have never submitted this, nor any part thereof, for the attainment of any other qualifications.

Signed. Signed by candidate
Derek Leisegang
August 2012

Abstract:

The South African wine industry has seen a growing interest in the field of renewable energy in recent years. This has been due, in part, to rising energy costs along with increased public and consumer awareness around the issues of global warming and sustainability. This project was conceived in the light of these developments, and centres on an investigation into the feasibility and design of a renewable-energy portfolio for the Klein Constantia Wine Estate, located in the Western Cape.

A literature survey was undertaken, shedding light on the common uses of energy on wine farms, renewable energy initiatives within the industry and the technologies available. A case study was then conducted using Klein Constanta Wine Estate as the subject. Physical measurements were taken where possible and, along with a combination of topographical, satellite and local climate data, were used to develop estimates for the energy-generation potential of the farm's renewable resources and the cost implications thereof. Following this, a qualitative and quantitative analysis was conducted to determine the most favourable technologies from a portfolio design perspective. From these findings, three potential portfolio designs were developed, each covering varying degrees of the farm's energy consumption.

Based on these final designs, it was concluded that there was indeed significant potential for investment in renewable energy at Klein Constantia; and that the farm could more than cover its energy requirements. While the financial returns would be minimal, with relatively long payback-periods, the secondary benefits to the farm were considered to be sufficient to justify the investments. The final decision, however, would likely rest on the weight given to the secondary benefits by the farm owners.

It was also determined that, in the case of Klein Constantia, the larger the investment the less secure it would be. This was primarily due to the need for higher-risk and more expensive technology options being required when the energy target was raised. With this in mind a renewable energy portfolio, covering only the farm's electricity use, was found to be the most favourable option available to the farm.

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BD	Blade diameter (ft^2)
AEP	Annual Energy production (kWh)
O_w	Average annual wind velocity (m/s)
$Ppot$	Potential power generated (W)
ηsys	Overall system efficiency
ρw	The density of water (kg/m^3)
g	The gravitational constant (9.812)
hg	The available head (in metres)
$Qpipe$	The flow-rate (litres/second)
PP	Payback period (years)
IC	Initial capital investment (ZAR)
AS	Annual Savings Accrued (ZAR)
AM	Annual O&M costs (ZAR)
NPV	Net present value (ZAR)
C_o	Initial capital investment (ZAR)
T	Time period (Years)
C	Cash flow (ZAR)
r	Discount rate (%)
IRR	Internal rate of return (%)
EC	The final cost of the generated energy (ZAR/kWh)
$TLCC$	The total life-cycle costs of the project (ZAR)
TE	The electricity generated over the life-time of the project (kWh)

List of abbreviations

RE	Renewable energy
DOE	Department of Energy
DET	Department of environmental affairs and tourism
DME	Department of minerals and energy
UK	United Kingdom
IPW	Integrated production of Wine
PV	Photovoltaic
NASA	National Aeronautics and Space Administration
USDOE	United State department of energy
AEP	Annual energy production
BD	Blade diameter
kW	Kilowatt
m	Metres
KC	Klein Constantia
SABS	South African Bureau of Standards
CTIA	Cape Town International Airport
SANWS	South African National Weather Service
kWh	Kilowatt hours
h	Hectares
kWp	Kilowatts at peak power output
SWH	Solar Water Heater
KWP	Kestrel Wind Power
EES	Earthpower energy solutions
VHS	Vortex hydro Systems
PP	Payback Period
ZAR	South Africa Rand
IRR	Internal Rate of Return
NPV	Net Present Value
EC	Energy Cost
CoC	Cost of capital
O&M	Operation and Maintenance
EIA	Environmental Impact Assessment
UNDP	United Nations Development Program
GHG	Greenhouse-Gas

Chapter 1 - Introduction

1.1 Background

Winemaking is an important part of the South Africa's cultural heritage, with the first recorded wine-farms dating back as early as the sixteen hundreds. Since then, South African wines have become known throughout the world and have played a significant role in the development and economic growth of the Western Cape.

Historically, world wine markets have been dominated by the major European producers such as France, Italy and Spain. In recent decades, however, increases in worldwide consumption have led to a number of other countries expanding their wine production levels. These so-called 'new-world' producers include the USA, Australia, Canada and South Africa, amongst many others.

The recent growth experienced by the industry, while invariably being good for the consumer, has resulted in higher levels of competition between producers. This increased competition has led to the need for wine-farms to find ever more innovative ways by which to produce and to differentiate their products from the growing list of new competitors. One avenue of innovation, that has received significant interest in recent years, is that of energy.

With increased public awareness of issues relating to the environment, global-warming and climate change, a number of wineries have turned to renewable-energy (RE) as a means by which to reduce their carbon-footprints and to place their wines in the emerging category of 'eco-friendly' consumer products. These measures have been further bolstered by the introduction of retailer-driven restrictions, within in some European countries, of products that do not meet prescribed environmental standards.

It is in the light of these developments, along with the recent increases in electricity prices, that numerous South African wine-farmers have begun to explore the possibility of renewable-energy. This project, through the use of a case study, sought to explore some of the renewable resources available one such farm and to determine whether they were sufficient to replace the farm's coal-derived energy needs.

1.2 Objective of the study

The farm chosen for the case study was Klein Constantia, a well-know wine-estate located in the outer suburbs of Cape Town. Following the choice in farm, the primary objective of the study was narrowed down to the following basic sentence:

"To determine whether Klein Constantia wine-estate could feasibly replace its fossil-fuel-derived energy usage with electricity generated using the farm's own renewable-energy resources."

This primary objective was then split up into a number of smaller, more specific project goals. These were as follows:

- *To conduct a basic site-analysis of the Klein Constantia estate, and to determine the scope and scale of the renewable resources available for energy generation.*

- *To assess the feasibility of a variety of renewable-energy technologies on the basis of a set qualitative and quantitative design parameters.*

- *To design and propose the layout of three renewable energy systems that would cover the following scenarios:*
  1. *The maximum amount of energy that could be generated by the farm.*
  2. *To replace the farm's electricity and fuel consumption.*
  3. *To replace the farm's electricity consumption.*

- *Based on the findings, to draw conclusions on the overall feasibility of renewable-energy at Klein Constantia; and to suggest avenues for possible further study.*

1.3 Scope

With these objectives in mind, a scope was developed that would allow for an adequate exploration of the topic, while at the same time keeping the requirements within the desired time frame. The scope of the study was therefore determined by the following factors:

- The renewable resources were limited to Solar, Wind, Hydro and Biomass.
- Only Klein Constantia's resources were considered to be available for energy generation (i.e. external resources such as biomass from neighbouring farms were not considered).
- The technologies explored were limited to Solar-PV, Micro-Hydro, Small-Wind, Biogas Digesters and Solar Water Heaters.
- The site, cost and energy estimations were limited to sources, formulas and calculations that would not require detailed site measurement, product specifications or lengthy time periods.
- Energy-efficiency measures were not considered as part of the study.
- It was assumed that the farm would be able to negotiate a one-to-one net metering agreement with the municipality, thereby allowing excess energy to be stored on the grid.
- It was assumed that the electricity price would increase at the rate of inflation for the duration of the technologies' lifespans.

1.4 Report Outline

This report begins with a literature survey in which the topics of energy-use and RE-generation are explored within the context of the South African wine industry.
The third chapter documents the site-analysis carried out on Klein Constantia farm, along with the processes used to determine the generation potential of the farm's

various renewable resources. Chapter four explores the practical limitations and design parameters used to determine the most favourable technology options and their overall feasibility. In chapter five, three different energy-scenarios are explored in order to determine the energy mix required to meet the various needs of the farm. Finally, based on the findings, conclusions are drawn, along with recommendations for further study.

Chapter 2 - Literature survey

2.1 Overview of the global wine industry

The majority of the world's wine production is concentrated in a relatively small number of countries, located between the latitudes of 30° and 50° in both the Northern and Southern hemispheres (Tonietto & Carbonneau, 2004). The influence and impact, however, of the global wine industry stretches from these grape-growing regions through to almost every country in the world.

In 2005, the industry produced more than 286 175 000 hectolitres of wine from the almost eight million hectares of farmland under vine (Smyth & Russell, 2009). Of this total, the 'old world' regions of Spain, Germany, France and Italy contributed the highest to production volumes, and continue to produce the majority of the world's wine.

In the last three decades, however, many 'new world' regions have seen tremendous growth in their production, trade and consumption of wine products (Campbell & Guibert, 2006). This growth has been accompanied by increased positive public perceptions regarding the quality and pedigree of 'new world' wines, to the extent that the 'old world' dominance is being rapidly diminished to make way for a more balanced global industry (Aylward, 2003).

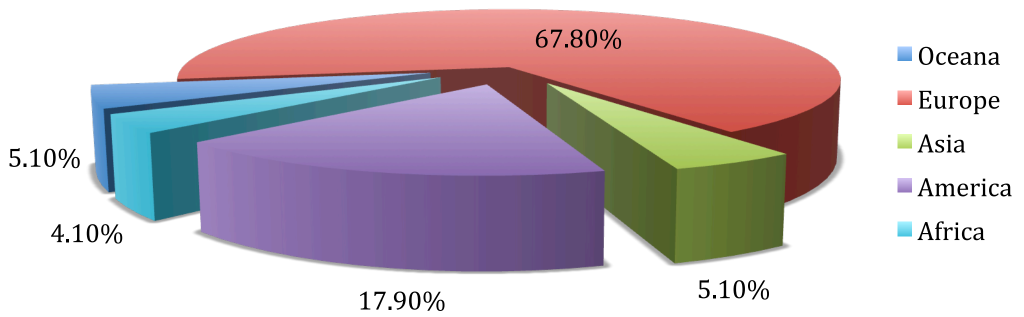


Figure 1: Contributors to the world wine-production by volume (Vázquez-Rowe et al, 2011).

As a large player in world food and beverage markets, the wine industry consumes a significant amount of energy and other resources. It was estimated, in 2008, that 105PJ of energy was consumed by the global wine industry, resulting in carbon emissions totalling 16 million tons. This figure, however, did not include emissions from secondary industries such as transport and bottle production. With these associated industries taken into account, the carbon footprint was estimated to be over 76 million tons (Smyth & Russell, 2009).

2.2 Brief history of wine in South Africa

Wine in South Africa dates as far back as the 17th century when Jan van Riebeeck, Dutch commander of the Cape colony, first initiated the planting of grapevines in Cape Town in 1655. These first vines, thought to originate from France, were planted in a section of the, newly established, Company Gardens; and produced their first wine in February of 1659 (Haddad, 2003).

Simon van der Stel, who succeeded Jan van Riebeeck as Commander of the Cape in 1659, brought with him a significant amount of knowledge and enthusiasm for viticulture. He designed the, now famous, Constantia Estate as a model-farm for other prospective farmers to base their designs on. He also identified the significant potential of the Wildebosch valley, beneath the Hottentots Holland Mountains, and renamed it Stellenbosch. In so doing, he established the town that would later become the one of the most important contributors to the Western Cape wine region (Hench, 1984). Through the proceeding centuries, the South African wine industry continued to grow, with vineyards being planted as far North as the Orange River and as far east as Kwa-Zulu Natal. The Cape, however, remained the focal point of the industry with the introduction of French Huguenots to the Cape in the 17th Century contributing greatly to the growth in knowledge and the addition of new cultivars.

Political and economic developments, both locally and abroad, contributed to significant fluctuations in the demand for South African wine over the years. Historical events like the 19th century Napoleonic wars and, more recently, the Apartheid regime all had a marked effect on the demand, development and reputation of South African wines (Haddad, 2003). In recent years, South Africa has seen a renewed interest and growth in its wine industry; and, along with many other 'new world' regions, is set to continue this growth into the future (Aylward, 2003).

2.3 Overview of the South African wine industry

Wine production in South African is focused mainly in the Western Cape. However, a small but significant portion of land is also under vine in the Northern Cape, mostly along the banks of the Orange River.

Figure 2: The wine regions of the Western and Northern Cape (Blackcspirits, 2012).

As of September 2011, there were just over 111 000 hectares of wine-grape vineyards under cultivation in South Africa. Of these, 9024.6 hectares were dedicated to the production of brandy, with the remaining 101 016.2 hectares being used for the production of wine (Sawis, 2011).

According to Sawis (2011) the amount of natural wine produced in South Africa in the year 2010 totalled 780 million litres. This puts South Africa at 9th in the world wine volume production rankings, with the country producing just over three percent of the world's wine (Campbell & Guibert, 2006). Over half of all South African wine is exported, making wine the nation's 17th largest export commodity. In 2008, exports totalled over R6.2 billion; up from R3.4 billion in 2004 (Sawis, 2009).

In terms of energy use, it is estimated that agriculture in South Africa currently constitutes between to 2.5 and 3% of the total primary energy demand, with a total of 70 000 TJ being consumed annually (DOE, 2009). This translates into over 35 000 Gg CO_2 equivalent emissions (DET, 2009).
Of the total energy use in the agricultural sector, electricity and diesel are, by far, the largest contributors amongst commercial farmers, jointly comprising over 65% of the energy used (DME, 1998).

Within the agricultural sector of South Africa, the wine industry is a relatively small energy consumer when compared to larger industries like maize, wheat, sunflowers and cattle. The wine industry does, however, contribute a significant amount to the export earnings of the sector; and could certainly play a role in paving the way for further development in renewables within agriculture in South Africa (BFAP, 2010).

2.4 Incentives for renewable energy development in South Africa

There are numerous incentives that could potentially play a role in the development of renewable energy use in the South African wine industry. Some of these are explored below:

With the recent growth in public knowledge and awareness of climate change and other environmental issues; consumer demand, particularly in the food and beverage industry, has trended more and more towards environmentally friendly products. Forbes et al. (2009) showed that in New Zealand and the UK, for example, there is a strong consumer demand for environmentally sustainable wines, and that the consumers are prepared to pay a premium for them. It was also shown that they considered 'green' wines to be of an equal or higher quality than conventionally produced wines. According to McBride (1999) while the quality and taste of wines are still the most important factors to consumers; more and more, the environmental status of the wine is starting to influence decision-making.

Retailers, regulators and government legislators have also played a significant role in the development and promotion of 'green' practices within the global food and beverage industry (Forbes, Cohen, Cullen, & Wratten, 2009). According to the South African Food and Wine Initiative (2009) several international retailers have already launched significant campaigns centering on climate change and the environment; thereby placing increasing pressure on South African exporters to reduce the greenhouse-gas emissions associated with their products. In response to these pressures, a number of winegrowers associations and bodies, around the world, have also launched environmental schemes and initiatives in recent years.

In South Africa, in 1998, the Integrated Production of Wine (IPW) scheme was launched with a view to increasing the environmental sustainability of South African wines. Compliance with the scheme entitles the wineries to place a compliance seal onto their bottles. This can then be used as a marketing tool, along with other compliance certificates like the ISO 14001, which has already been adopted by a number of wine farms in the Western Cape (Knowles & Hill, 2000).

Marketing has also played a significant role in the emergence of new-world wines, with innovation now being one of the key positive perceptions often associated with new-world products (Aylward & Turpin, 2003). In recent years, these winemakers have begun to challenge the old-world for market share in both established and emerging markets. A big part of their challenge has been to shed the, often negative, perceptions that surround new-world wines when compared with more established winemaking regions. With this in mind, marketing has and continues to play a very significant role the development and growth of the new-world's wine industry, and environmental initiatives can contribute significantly to marketing strategies (Campbell & Guibert, 2006).

With regards to government driven incentives, the South African government has set ambitious renewable energy targets for the country, along with numerous proposals of how these targets might be achieved. These measures have sparked significant interest in renewable energy in South Africa in recent years and, together with the proposed long-term mitigation and energy efficiency strategies, have succeeded in raising the levels of public awareness of energy matters.

Finally, in the light of escalating conventional energy costs and the declining cost of renewables, the adoption of renewable energy technologies has become increasingly more viable from a cost perspective. With diesel and electricity prices reaching record highs in South Africa in 2011, and with further increases set to occur in the coming years; many energy-technology investments that may have once seemed prohibitively expensive are starting to become significantly more viable.

All of these factors, and many more, have likely contributed to the significant growth and development of environmental initiatives within the South African wine industry in recent years. While wide-scale investment in renewables is yet to be realised, the pressures and incentives for change have been steadily increasing, forcing many farmers to rethink their long-term energy strategies.

2.5 Renewable energy initiatives in South Africa's wine industry

In the last decade, a number of wine-farms in the Western Cape have made a variety of investments in renewable energy. While the vast majority of these projects have been relatively small and isolated in their impact, a few farms have taken significant strides towards achieving more comprehensive energy and environmental strategies.

In 2006 Backsberg Winery, located near Paarl, became the first winery in South Africa and the third one in the world to be certified carbon-neutral (Opengreenmap, 2009). This was initially achieved through carbon offsetting in the form of tree planting in the nearby village of Klapmuts. Since 2006, however, the farm's energy strategy has developed significantly to include components such as bio-digesters, biofuels, extensive energy-efficiency measures, and a variety of other projects aimed at reducing the carbon intensity of the farm's operations (Urbansprout, 2009).

Following along a similar track, in 2010, Villiera Winery, based in Stellenbosch, set about trying to reduce its carbon footprint. These efforts culminated in the installation, in late 2010, of a 132 kWp solar-photovoltaic (PV) system. The system, comprising a total of 539 panels, was installed onto the roofs of three of the farm buildings, and covers an area of 900m^2. The energy produced is able to supply the entire day-time electrical needs of the farm, outside of harvest time, including the cellars, housing, offices, processing and bottling plants (Energworx, 2010).

An example of a winery taking strides towards sustainability, in a slightly different direction, is the Tokara Wine Estate in Stellenbosch. In 2006, the winery transferred its entire fleet of diggers, utility vehicles and tractors onto bio-diesel. The bio-diesel is made from domestically produced vegetable oil, and has allowed the farm to significantly reduce its carbon-footprint (McLaren, 2006).

These and numerous other projects around the Western Cape have demonstrated the growing interest in renewable technologies in the local wine industry. They still, however, represent only a small part of the total industry, leaving significant room for the expansion across the rest of the Western Cape.

2.6 Energy breakdown of wine farms

There are numerous processes and activities that account for the energy use on wine farms. While many of these consume energy throughout the year, a number are also seasonally dependent and differ significantly from month to month. Of the energy carriers, electricity, petroleum and diesel account for almost all of the energy consumed (Smyth & Russell, 2009).

The energy use in winemaking can be broken down into a number of composite activities, as listed below:

- Vineyard planting and maintenance
- Harvesting
- De-stemming and crushing
- Pressing
- Fermentation
- Clarification
- Aging
- Bottling
- Distribution
- Other farm operations (lighting, electricity in farm houses, restaurants)

These activities often involve a variety of different energy sources and some are significantly more energy-intensive than others. There can also be a large degree of variation from farm to farm in terms of methods used, and processes followed.

2.6.1 Planting, maintenance and harvesting

These three activities have relatively high-energy demands, with planting and harvesting taking place over short periods of high-intensity compared with vineyard maintenance, which is in operation throughout the year. The majority of the energy consumed is in the form of diesel, which is used to power the tractors and farm machinery that carry out the various activities such as ploughing, spraying, trimming and harvesting.

The fuel consumption depends on the efficiency of the vehicles and machinery, and the number of times they are required to pass through the vineyards during operation. Machines that are able to perform more than one function at a time are, therefore, often more energy-efficient that single use machines (Schnepf, 2004).

Before planting, the fields usually need to be sub-soiled (laying down the bed of earth directly beneath the topsoil). Ploughing, harrowing and the establishment of suitable drainage follow this. Fertilizers are often used to supply the desired nutrients to the soil, and chemical sprays are used keep pests under control. Grass cutting, row grubbing (clearing of roots and stumps) and trellis management are then employed throughout the year to keep the vineyards in good order (Smyth & Russell, 2009). When dealing with higher-end wines, the harvesting itself is often done by hand. Diesel, however, is still required to transport the harvested grapes from the vineyards to the cellar.

Irrigation can sometimes also require significant energy inputs during the dry summer season. In some cases irrigation can be gravity fed, but in most situations diesel or electrically powered pumps are used to pump the water around the farm.

All these processes are very mechanically intensive, and thus contribute to the significant amounts of energy consumed by this part of the winemaking process. After harvesting, the grapes are transported to winery.

2.6.2 De-stemming and crushing

This is the next process to occur after harvesting. The grapes are first moved into the receiving bay, usually by crane, and then transported around the cellar via a selection of screw conveyors and pumps. During this process, the stems are removed from the berries and the grapes are crushed to produce a mixture known as *must*.

Depending on the type of wine being produced and the temperature of the grapes at the time of picking, the *must* may need to be cooled (Neelis, et al., 2008). It is then transferred either to the pressing stage or onwards to the fermenting tanks. Electricity is the direct or indirect energy source for most of the machinery used in this section of the process; and is used to power the compressed air, pumping, cooling and crushing operations (Smyth & Russell, 2009).

2.6.3 Pressing

In the case of white wine production, the next process after crushing is that of pressing. If red wine is being produced, however, the *must* is pumped straight to the fermenting tanks, and pressed after fermentation.

Pressing is usually the primary method by which the juice or wine is separated from the pulp, seeds and skins. While a small number of wineries do not use pressing, rather opting for the smaller quantity of free-run-juice released upon crushing; the majority of wineries do use it as it allows for the maximum amount of juice to be extracted from the grapes. The speed and pressure of the press can have a significant effect on the quality of the juice produced. As a result, the process is carefully controlled with the pressure typically kept below 2 bars (Smyth & Russell, 2009). The most common type of press is the membrane press, which produces a higher quality juice compared with other technologies. A membrane press relies on a variety of electrically driven machinery including motors, compressors and pumps.

Typically, one ton of grapes produce between 450 and 600 litres of juice. The remaining mixture of pulp, seeds and skins, called the marc, is transferred out of the winery via conveyors, and can be loaded onto trucks for further distribution or processing (Neelis, et al., 2008).

2.6.4 Fermentation

The process of fermentation is one of the largest consumers of energy within a winery and usually lasts between 7 and 30 days. The energy consumed, in the form of electricity, is used primarily for cooling.

Depending on whether red or white wine is being produced, the must or free-run juice is pumped into large fermentation tanks. The tanks are usually made of stainless steel, however, some wineries also use oak barrels. Yeast is then added to the mixture, which converts the sugars in the grape-juice into alcohol and carbon dioxide; and a by-product of this reaction is the production of heat. The temperature of the mixture, however, is required to be kept within specific limits during the fermentation process. The tanks, therefore, often require significant amounts of cooling, and sometimes heating. This accounts for the majority of the energy consumed in the process; and is often achieved through the use electrically powered refrigeration jackets that surround the fermentation tanks.

When red wine is fermented the skins, pulp and seeds float to the top of the tank, forming a solid cake. This cake layer sometimes needs to be broken from time to time during the process. This is can be achieved through the use of mechanical punching or stirring machines; or through the use of ‘rototanks’, which turn the entire tank upside down in order to break up the cake (Neelis, et al., 2008).

2.6.5 Clarification

Clarification is the process by which the last remaining yeast cells and other solids are separated from the wine. This can be achieved through a number of techniques, with varying energy intensities. Electricity is once again, the primary source of energy for the process which can include processes such as filtration, racking, centrifugation and electro-dialysis (Smyth & Russell, 2009).

2.6.6 Ageing

Ageing and storage follows the clarification process. The wine is aged for varying amounts of time, in a cool environment, in either large stainless steel tanks or oak barrels. The cool temperatures can be achieved through a variety of renewable methods (such as reverse heat-pumps and river water cooling); however, electrically powered air-conditioning is often relied upon (Neelis, et al., 2008).

2.6.7 Bottling and further storage

The last step in the process of wine making is the bottling and corking. This process can be done in-house or it can be outsourced, depending on the scale and quality of production.

The process involves the pumping of the wine through to tanks at the bottling facility. The wine is often filtered once again to remove any final impurities and is then pumped or gravity fed into the bottles. Corks are then placed into the bottles, leaving a small air gap between the cork and wine (Smyth & Russell, 2009).

These processes can be achieved through a variety of methods; and can vary from simple, labour-intensive methods through to highly automated processes that consume significantly more electricity. The bottles, once corked, are dried, labelled and then stored, in a cool, dark environment, ready for transport.

2.6.8 General other

Apart from the energy directly consumed in the winemaking process, most wine farms also consume a significant amount of energy in the various secondary processes associated with the operations of the winery and the farm in general.

For the winery, these can include cleaning, lighting, waste-management and a variety of other activities that don’t contribute directly to the wine making process.
The winery aside, however, further requirements often include power for offices, security, transport and housing; along with commercial activities like hotels and restaurants.

When added together, these secondary activities can contribute a significant portion to the farms overall energy consumption (Smyth & Russell, 2009).

2.7 Renewable technologies applicable to the wine industry

This sub-chapter explores the five renewable energy technologies that were considered for the Klein Constantia farm as part of this study. These included solar-PV, micro-hydro, small-wind, biogas digesters and solar water heaters.

2.7.1 Solar PV

Photovoltaic (PV) panels represent one of the most important renewable energy technologies available to the wine industry. The term ‘Solar PV’ refers to electricity garnered specifically from the sun’s rays.

Basics of the technology:

Photovoltaic (PV) cells convert light energy, in the form of photons, into electrical current through the use of the photoelectric effect (NASA, 2002). A solar cell consists of a semi-conductor material, usually in the form of a thin silicon wafer, which is treated to form an electric field between its front the back face. When light strikes the surface of the semi-conductor material, electrons are excited and flow from the negative to the positive side of the wafer, thereby creating an electric current (Energy Savings Trust, 2011).

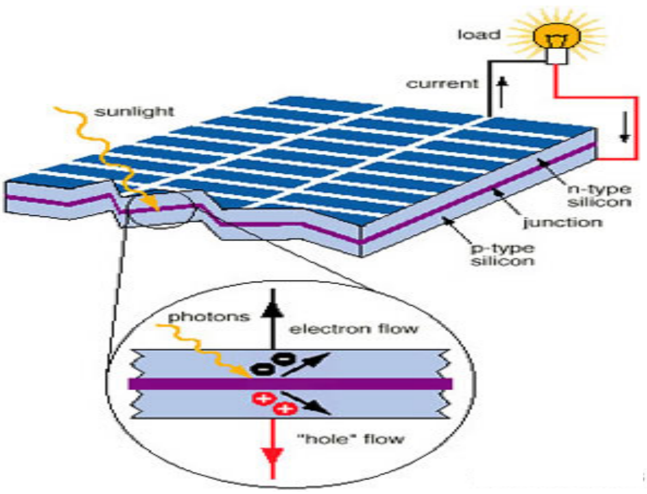


Figure 3: The basic operation of a solar PV cell (Star Solar, 2012)

Solar cells can be connected together to form a photovoltaic module. A number of modules can then be connected together to form a solar panel, with a combination of these being called a solar array.

The panels produce direct-current electricity and are designed to provide this electricity at a constant voltage, with the magnitude of the current depending on the intensity of the sunlight striking the surface of the panel. These can then be connected together in series or parallel combinations to suit the load requirements (NASA, 2002).

There is a significant difference between the solar power incident upon a PV panel and the final electrical power that the panel is able to supply. This difference is caused by inefficiencies in the energy conversion process within the solar cells, along with issues like reflection and other related external phenomena. The efficiency rating of a particular solar panel varies form one manufacturer to the next and also depends on the type of PV technology in use. As a result of this, the rated efficiency of solar panels can vary from 5% through to 43.5% (NREL, 2011). While single layer silicon cells have a theoretical efficiency limit of 37.7%, multi-layer cells have a theoretical limit of 86%. The standard efficiency of the panels available commercially in South Africa, at the time of this study, was expected to be between 13 and 16% (MLT Drives, 2012).

Batteries can be used to store the electricity captured, but would also add significantly to the cost and maintenance requirements of the system. Batteries are therefore particularly applicable to rural areas where there is no access to the grid. In urban areas a PV system could feasibly be connected, via an inverter, to the grid to allow for net-metering (Eco2Solar, 2011).

Determining a site's potential energy yield:

The potential of a specific location to produce PV power is determined by a number of factors. Local climate naturally plays a significant role in this regard and is often closely connected with the site's degree of latitude. These two factors affect the average intensity of the suns irradiation, the prevalence of cloud cover and the hours of available sunlight, all of which contribute to the site's PV potential.

Regarding the angle of panel-tilt, much literature has been devoted to determining the ideal angle of tilt for different latitudes and for different times of year. Numerous mounting devices have also been developed that are able to track the suns progress through the day, or on a seasonal basis. Due to the limited scope of this study, however, a simpler approach was followed. A rule of thumb exists within the solar-power industry which states that for the approximate best all-year-round performance of a solar panel, the panel should be tilted to match the latitude of the site in question (Watson & Watson, 2011). A fixed tilt angle of 33 degrees 55 minutes south was therefore assumed for the duration of this study.

Solar data for a site can be sourced in a variety of ways including using ground data from nearby weather stations, making use of satellite images or solar maps, or through the installation of a small weather station at the specific site. The collected data can include Direct-normal, Diffused-horizontal and Global-horizontal radiation. The measure of irradiation that is most significant to PV power, however, is that of Latitude-tilt irradiation. This is a measure of the combined direct and diffuse irradiation incident upon a surface tilted to match the site's latitude (Meyer, 2010).

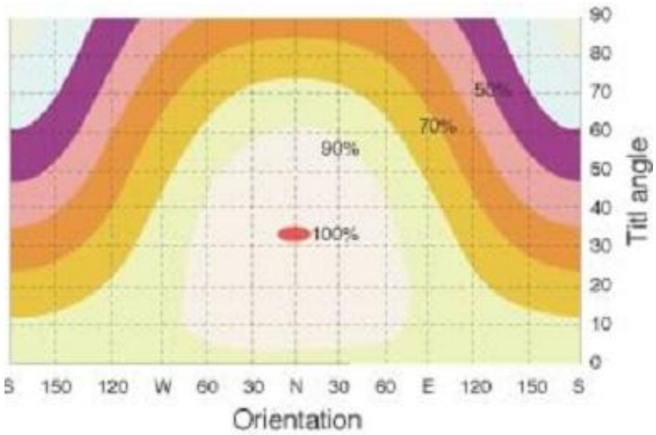


Figure 4: PV panel efficiency according to the direction faced and tilt-angle of the panel at the latitude of 35 ° S (Stapleton & Milne, 2010)

2.7.2 Solar Water Heaters

Solar water heating is an established technology within the Western Cape and is one of the simpler renewable energy options available to Klein Constantia.

Basics of the technology

In short, the technology harnesses the suns radiation as an energy source for the heating of water or solar-fluid. The water or fluid is then either passed through a heat exchange or is transferred directly to an insulated storage tank. This heated water can then by drawn off for use in a variety of applications.

To accommodate the differences in climate, budget and the specific needs of the user, numerous permutations of the technology have been developed. These range from simple and inexpensive direct and passively operated systems through to indirect, active systems with back up electrical heating and the ability to operate in sub-zero temperatures (Retscreen, 2004). There are, however, three major components common to all solar water heaters, namely the solar-collectors, the storage tanks and the liquid transfer systems.

Solar-collectors are used to capture heat from the sun and to transfer it to the working fluid of the heater. The collection technologies range from simple black tanks or pipes through to the more modern evacuated-tube collectors, which give off minimal heat loss to the surrounding air (USDOE, 2011). The principles that guide the orientation and angle of tilt of PV-panel installation also apply to the use of solar-water heaters (USDOE, 2011).

The storage tanks are usually insulated containers that store the heated water for use at a later stage. In systems with combined electrical heating, the solar tank is sometimes separated from the conventional hot-water tank. The most common configuration however is the single-tank system, where the solar-water heater tank is combined with the electrical backup system to form an efficient, well-insulated unit (USDOE, 2011).

Figure 5: An example of a simple solar water heater (Starsolar, 2011)

The liquid transfer system refers to the various pipes, pumps and conduits connecting the solar collectors to the storage tank. In areas where the temperatures drop below freezing, indirect circulation systems, which make use of non-freezing heat-transfer fluids, are used to prevent freeze-damage to the collector pipes. The heated fluid is then passed through a heat exchanger where the energy is transferred to the water for storage and use (NREL, 2006).

2.7.3 Wind

The use of wind power in agriculture has been around in South Africa for a number of years. This has primarily taken the form of the steel windmills, which have been used to pump water on farms throughout the country for many decades (DME, 2003). Using small-scale wind power to create electricity, however, is still relatively rare and, given the country's significant wind resources, was considered worth investigating further.

Basics of the technology

Wind turbines harness the energy of the wind by converting the kinetic energy of the moving air into mechanical power in the spinning turbine blades and shaft. This power is then converted into electrical energy through the use of a generator (Windeis, 2012). There are two main types of wind turbines available: vertical-axis and horizontal-axis. Vertical axis turbines are relatively rare in comparison to their horizontal-axis counterparts.

Wind turbines range in size from a few hundred watts through to as much as 10MW; and have a theoretical maximum efficiency of 59.3%, as determined by German physicist Albert Betz in 1919 (Brosius, 2009).

Figure 6: An example of a horizontal axis wind turbine (Wolf Solar-electric, 2012)

Typical small-scale wind turbines, however, usually operate with efficiencies of below 35%, even in optimal wind conditions. This is often due to a variety of issues including storage, engineering and cost constraints, along with transmission losses (Greenspec, 2010).

Careful positioning of the turbines play a significant role in harnessing the optimal wind potential of a site. Wind turbulence, caused by nearby obstacles located in the wind-path, has a negative effect on the efficiency of a wind-turbine and therefore should be avoided wherever possible. The height above the ground also plays an important role, as average wind velocities at any given site tend to increase with an increase in elevation. For these and other reasons, wind turbines are often located in elevated positions on towers, roofs and hill-tops (Greenspec, 2010).

Various rules of thumb have been developed within the wind industry to guide the installation of small-scale wind-turbines. One of which, regarding the installation of a turbine onto a roof, states that a wind turbine should be installed at around 10m above the highest point of the roof and preferable 100m away from the nearest obstacles in the wind-path. Another, regarding the installation of a freestanding turbine tower, states that the bottom of the rotor blades should be at least 6m above any obstacle located within 76m of the tower (Southwest, 2010).

Determining a site's potential energy yield:

Wind data can be acquired from numerous sources including local wind-maps, nearby weather stations, airports, universities and small-scale private weather stations within the locale of the proposed turbine site. However, the most accurate and reliable wind data is acquired by conducting a wind resource assessment at the site in question. For many sites, though, the cost of an assessment is a prohibitively high, thereby necessitating the use of other sources (Southwest, 2010).

The acquired data can then be used to determine the amount of energy that the site is likely to generate in a given year. One method, which can be used when sufficient data is available, is to combine the wind-speed distribution curve of the site with the power curve of the turbine.

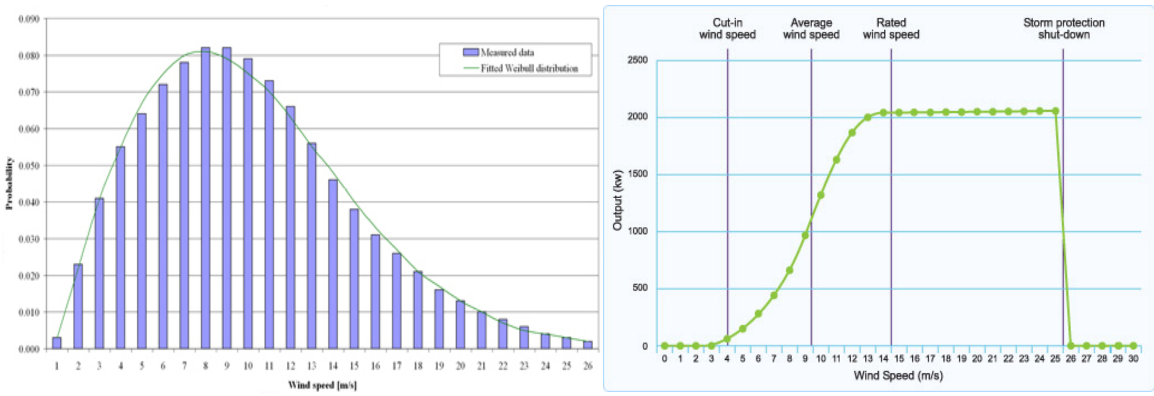


Figure 7: Wind distribution curve and a turbine power curve (PFR, 2010 & WETF, 2009).

The wind-speed distribution curve shows the frequency with which the various wind speeds occur throughout the year, while the power curve shows the turbine's power output according to each of these speeds. Therefore, when the power output at each wind-speed is multiplied by the number of hours that that wind speed occurs in a year, the annual energy production (AEP) can be determined by adding up the values for all the wind speeds (Brosius, 2009).

When insufficient site-specific data is available, the annual energy production of a turbine can also be determined using a simpler method. The rule-of-thumb formula for determining the annual energy production for a wind-turbine, based on the average wind speed and rotor diameter, is as follows (Smith, 2008):

$$AEP = (0.01328) \times (BD)^2 \times (O)^3 \qquad (1.1)$$

where AEP is the annual energy production in kWh, BD is the blade diameter in ft^2, and O is the annual average velocity of the wind in $m.s^{-1}$. While this method is not considered to be as accurate as the first, it does allow for the basic estimation of a site's AEP without the need for a complicated and costly site-assessment.

2.7.4 Biogas digesters

Biogas digesters form part of a range of renewable energy technologies that make use of biomass as their feedstock. Aside from digesters, other prominent technologies include bioethanol, biodiesel, gasification, pyrolysis and regular combustion. While all of these technologies were considered to have merit and would certainly have been able to produce energy, the scope of this study limited exploration to biogas alone. This was primarily due to the fact that biogas generation was considered to have numerous advantages over other forms of biomass technology, and was anticipated to provide the highest energy yield (Mattiasson & Börjesson, 2007).

The use of biogas digesters (bio-digesters) in agriculture has grown significantly over the last hundred years. While initially favoured as a waste-treatment process, in recent years more and more interest has been directed towards the energy yields that the process generates (UOA, 2002). South Africa has also seen a growing interest and subsequent increase in demand for bio-digesters. Within the wine-industry, however, the use of bio-digesters is still relatively rare.

A small number of projects around the world have highlighted the possibilities that exist for bio-energy generation from wine farm waste products. These projects have helped to shed light on a technology that could provide a significant amount of power, along with numerous other benefits, to wine farmers in the future. The most prominent of these projects, located on the Vandermeer farm in Ontario Canada, makes use of grape-pomace as the primary feedstock in its bio-digester plant. The plant, with an intake of 5 kilotons of grape pomace each year, produces over 730kW of continuous power for heating and electrical applications on the farm; and is able to offset a large portion of the farm's energy needs (AE, 2012).

Basics of the technology

Bio-digesters make use of a bacterial process called anaerobic-digestion to break down organic matter within an enclosed space. The process of digestion causes the build up of a collection of gasses; of which is methane is a large constituent. The methane can then be separated off from the other gasses, and used as a fuel to produce heat or electricity.

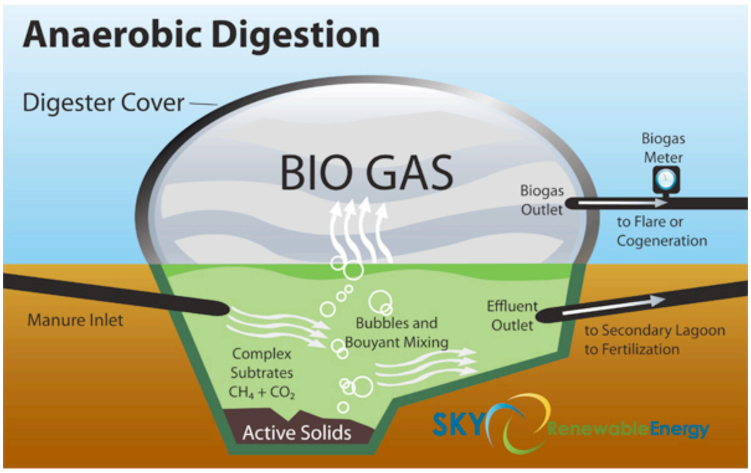


Figure 8: The basic operation of a simple biogas digester (VC, 2011)

A basic bio-digester is comprised of a sealed tank, an inlet for the digester feedstock, an outlet for the gas, and an effluent outlet. While other more complicated designs have been developed that provide higher efficiencies, further processing, different pressure designs and more automation; the basic premise has remained relatively unchanged.

Bio-digesters are able to operate using a wide variety of organic matter, called feedstock. The suitability of a particular feedstock depends on the time it takes to break down and the quantity of methane produced by this process. In this way, certain feedstocks like chicken litter or vegetable cuttings are able to produce more biogas at a greater rate than, for example, leaves or vine-offcuts.

The use of grape pomace (a combination of skins, juice and pulp) has been proven to be an effective feedstock in bio-digesters (AE, 2012). It is, however, most effective when combined with other organic matter like manure, human-waste and household vegetable scraps in order to create the ideal ratio of carbon to nitrogen for digestion to take place (Greenhouse Canada, 2010). Many of these suitable feedstock additions could potentially be sourced from wine farms with little or no need for extensive changes in infrastructure.

Determining the potential energy yield

An accurate prediction of the annual energy production from a bio-digester is ideally determined by a number of factors. These range from the amount and type of feedstock used, to the quality, size and correct management of the digester. A simpler method can be employed, however, that takes into account only type and quantity of feedstock available.

In this case, the expected biogas production levels are determined by assessing the specific feedstock being put into the digester, and looking at the retention time required for that feedstock (Melamu, 2012). When the expected methane output per kilogram of feedstock is known, along with the time taken for the gas to be produced, an estimate of annual energy yield can be determined.

2.7.5 Micro-Hydro

There are numerous small rivers and streams, located within the Western Cape wine region, which could be suitable for micro-hydro energy generation. Micro-Hydro is a well-developed and proven renewable energy technology; and is of particular value due to its ability to provide continuous power throughout the day and night. The term ‘micro-hydro’ refers to plants of the less than 100kW in size. This was the size considered most likely to be implemented by farmers in the Western Cape, as it is suited to small fast flowing rivers and streams.

Basics of the technology

Micro-hydro power plants make use of a turbine to convert the kinetic and potential energy of flowing water into rotational power on a spinning shaft. A generator or alternator is then connected to the shaft to convert this power into electrical energy.

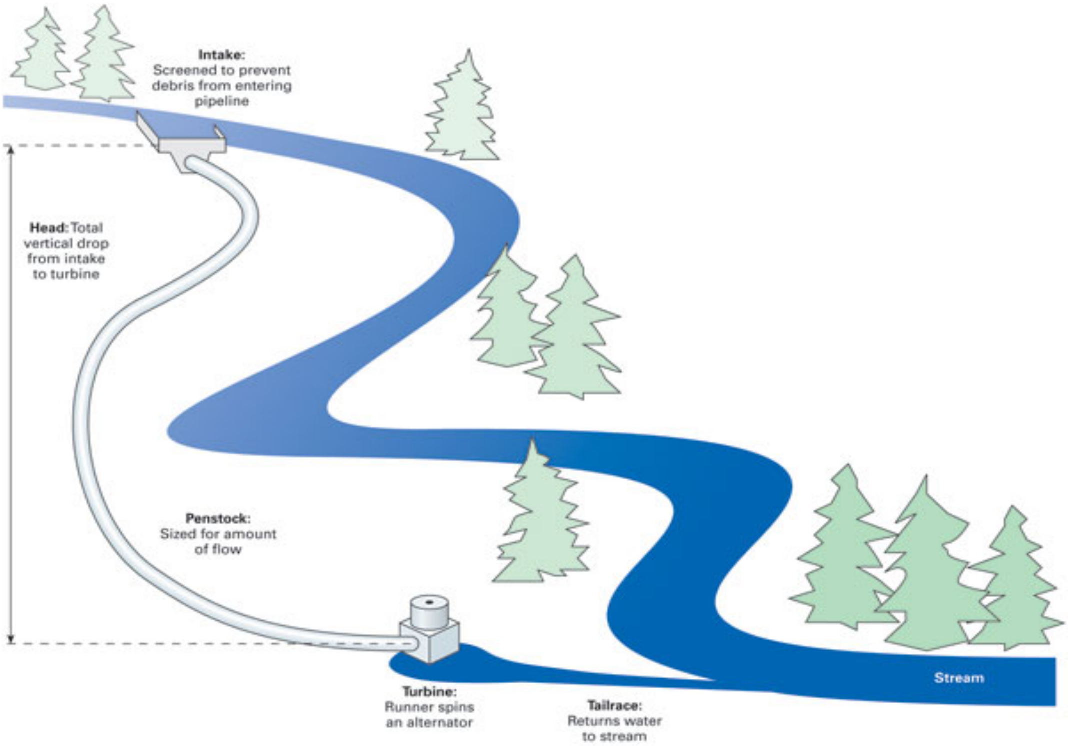


Figure 9: The basic layout of a micro-hydro plant (Homepower, 2012).

Micro-hydro systems are generally made up of the following basic components: the intake, penstock, powerhouse and tailrace. Each of these are explained in further detail below:

- The intake is the point at which part of the river or stream's flow is diverted away from the main flow into the micro-hydro system. It is important to ensure that any debris is directed away from the intake, as this could damage the turbine and reduce the efficiency of the plant. Intakes are therefore often built into small dams or weirs, and filters are often used to ensure that large debris is kept out of the system (Cunningham & Woofenden, 2011).

- The penstock refers to the piping that directs the water from the intake through to the turbine. The diameter of the pipe is determined by the flow rate of the water, and friction between the water and the pipe-wall needs to be kept to a minimum. In micro-hydro systems the penstock piping is often made of PVC or Polyethylene (Atkinson & Cunningham, 2011).

- The powerhouse is the building or shelter in which the turbine, generator, regulator and other electrical components are housed. It is important that these components be protected from the elements and the powerhouse serves this purpose. It is important to bear in mind that when building a powerhouse, cognisance needs to be taken of the flood-line of the river or stream in question so as to prevent flood-damage to the equipment during bad weather.

- The Tailrace is the name given to the channel or piping that directs the water from powerhouse back into the original river or stream.

There are two basic types of turbines available: impulse and reaction turbines:

- Impulse turbines use a nozzle to generate a water-jet. This jet is directed onto the turbine runners, which deflect the water causing a change in momentum and the subsequent transfer of energy from the jet to the turbine-shaft (Atkinson & Cunningham, 2011). Impulse turbines are often used in micro-hydro applications due to their comparatively low-cost and their ability to operate under reduced flow conditions (USDOE, 2011). A common type of impulse turbine used in micro-hydro applications is the Pelton Wheel, which can achieve efficiencies of close to 90%.

- Reaction turbines are fully enclosed within a pressure casing and use the change in pressure across the runner blades to impart a rotational force on the turbine shaft. While reaction turbines are very efficient and effective, most models are rarely used for micro-hydro applications due to their high costs and complex designs (USDOE, 2011). There are, however, a few less expensive propeller type reaction turbines that are in use. Kaplan Turbines, for example, are sometimes used in micro-hydro applications and can achieve efficiencies of above 90%.

Determining the potential energy yield

The two most important factors to consider when determining the potential energy yield of a micro-hydro system are the head and the flow rate. The head refers to the vertical change in elevation between the intake and the turbine, while the flow-rate refers to the rate of flow of water through the system (Cunningham & Woofenden, 2011). The basic equation used to calculate the theoretical power output of a hydropower facility is as follows:

$$\begin{aligned}\text{Power (kW)} = {} & \text{Head (m)} \times \text{Water density (kg/m}^3\text{)} \\ & \times \text{Flow rate (m}^3\text{/second)} \\ & \times \text{Gravitational constant (9.812)}\end{aligned} \tag{1.2}$$

The above equation, however, does not account for energy losses and inefficiencies within the system itself. These can range from frictional losses along the surface of the penstock wall, through to the inefficiencies in the energy conversion process within the turbine. These losses need to be taken into account when trying to anticipate the real power output of a micro-hydro system, rather than the theoretical maximum (Copower, 2011). The simplest method by which to achieve this is to attach a system-efficiency coefficient to the end of the above formula.

Chapter 3 - Site Analysis

The farm chosen as the site for this case study was Klein Constantia (KC), located in the southern suburbs of Cape Town. The farm was chosen for a number of reasons including its proximity to Cape Town, the availability of energy and climate data, and the interest and support shown by the farm manager and owner.

In 2010 the farm invested in a comprehensive set of aerial photographs along with numerous images detailing the topography, layout, solar-data and other aspects of the farm. Records of the farm's fuel usage, cellar operations and collected weather data were also made available. These sources, along with various personal interviews conducted with the wine-maker and other staff, provided the majority of the information used in the site analysis.

The chapter begins with a general overview of the farm and its energy requirements, followed by an analysis of the renewable energy resources available.

3.1. Basic overview of the farm

Klein Constantia is one of South Africa's oldest and most prestigious wine farms. It dates back to the late sixteen hundreds and forms part of the original "Constantia Estate" that was designed and built by Simon van der Stel, governor of the Cape Colony at the time (Hench, 1984).

Figure 10: Klein Constantia farm in context of greater Cape Town (Google, 2012)

The farm rose to particular prominence during the 19th century when its sweet dessert wine 'Vin De Constance' became popular amongst the European aristocracy. One of the most famous of these was Napoleon Bonaparte who is said to have had bottles shipped to him while in exile on St Helena Island (Kick, 2009).

Following Simon van der Stel's death, the Constantia Estate was split up into 3 smaller farms of which Klein Constantia was one, along with Groot Constantia and Bergvliet. The Klein Constantia estate is situated on the easterly slopes of the Vlakenberg Mountain, which forms part of the Table Mountain national park. The estate is spread out over 146 hectares, of which 87 hectares are currently under vine. The remainder of the estate is taken up by steep forested ridges and kloofs, which run along the top of the property, and a variety of farm buildings, fields, gardens and homesteads towards the bottom. The numerous buildings located within the estate include the wine cellar, offices, tasting rooms, sheds and various residences, including the main farmhouse.

Figure 11: The farm (centre) situated on the slopes of the Vlakenberg Mountain (Kick, 2009)

3.2 Water

The farm receives an average of around 1600mm of precipitation annually, with most of this rain falling between the months of April and October. As a result of this relatively high rainfall, there is usually a plentiful supply of fresh water available on the farm.

Two streams flow through the property, supplying water to a total of four naturally fed dams. The two largest dams, located towards the top of the estate, are the farm's primary irrigation dams and are used irrigate the vines during the hot summer months. The southerly stream is fed by two smaller tributaries and provides water for the two irrigation dams. The northerly stream is the smaller of the two, and supplies the farm with drinking water from a spring located at the top of the estate.

3.3 Elevation and slope

As Klein Constantia is located on the slopes of a mountain, there is a significant change in elevation from the top of the farm to the bottom. The highest point, located in the northerly corner of the farm, is at an elevation of around 445m, while the lowest point is 63m above sea level, in the easterly corner of the property. The two top dams (1&2) are located at elevations of 175m and 137m, while the two lower dams (3&4) are at elevations of 72m and 75m respectively.

Much of the farm is located on a relatively gradual slope (shown in green below), which increases rapidly as you move northwest towards the mountain.

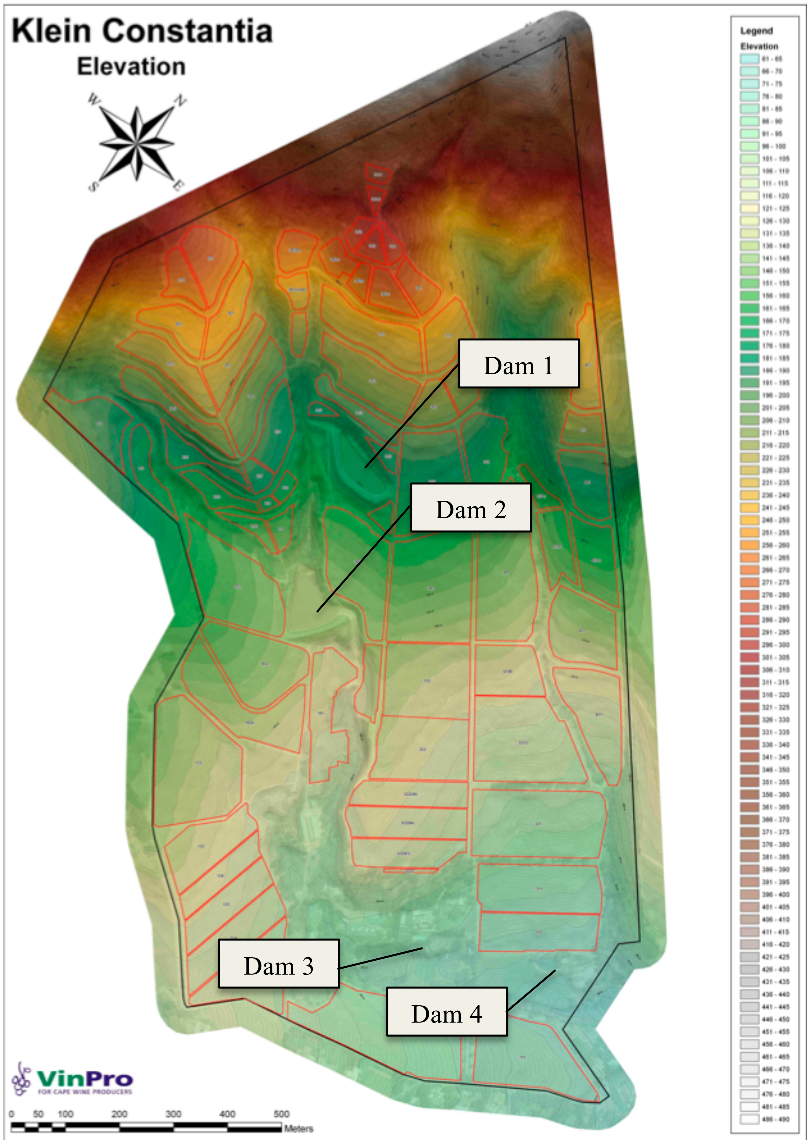


Figure 12: Elevation of the farm, showing the increase in altitude from SE to NW (VinPro, 2011)

3.4 Climate

Klein Constantia experiences a Mediterranean climate, typical of much of the Western Cape. This translates into cool wet winters and long dry summers. As mentioned earlier, the average annual precipitation is 1600mm. This falls mostly between the months of June and September. The farm's average rainfall is quite high in comparison to most other parts of the Western Cape, and this is due mainly to the orographic effect of the Vlakenberg Mountain.

The prevailing wind in the region is the south-easter, which blows for much of the summer. Another common wind is the Northwester, which usually heralds the arrival of a cold front. These winds are caused predominantly by the numerous low-pressure cells that pass over or close to the Southwestern tip of Africa.

3.5. Overview of the farm's energy usage

A number of sources were used to estimate the annual energy demand for Klein Constantia. First and foremost amongst these sources was an energy audit that was conducted on the farm, in early 2010, by DSV Consulting Engineers. Use was also made of the fuel usage and expenditure records, as provided by the wine-maker.

3.5.1 Electricity

Data on the farm's electricity usage, from 2004 through to 2010, was collected and collated when the energy audit was carried out. The total electricity consumed in 2004 was calculated to be 446 406 kWh. This had increased to 513 425 kWh by the end of 2009. This increase was primarily due to the installation, in 2006, of a new chiller-room and a high-pressure water-heating system for barrel washing. These two additions resulted in a year-end electricity consumption increase of 24.4%. Since 2006, however, the electricity consumption of the farm had steadily decreased by about 4% annually due to efficiency measures being employed on the farm. These efficiency measures ranged from changes in lighting through to the replacement of various cooling facilities within the cellar; and formed part of a drive by the farm managers to reduce the farm's overall electricity usage.

Tariffs:

The farm makes use of two municipal tariff systems for its electricity needs. The first is used by the various domestic residences on the farm and comprises approximately one fifth of the farms total electricity usage. The 'Domestic' tariff structure, in use as of January 2012 and excluding VAT, had an initial charge of R1.07/kWh for the first 600 kWh, rising to R1.18/kWh for the remaining usage.

The second tariff structure, which covered the remaining four-fifths of the farms electricity usage, was the 'Small-power-user' tariff. This electricity was charged at a standard fee of R0.9315/kWh along with a daily service charge of R17.20.

When the two tariff structures were combined, according to their respective contributions to the farms overall power consumption, an average figure of 98.13 c/kWh was reached. This figure was therefore chosen to represent the farm's general Eskom electricity charge, covering both tariffs, and was used in the financial analysis.

Energy total for electricity usage:

The total electricity consumption records from the farms two tariffs were combined to produce the annual electricity usage. The most recent, complete and up-to-date records available for the farms total consumption was for the year 2008/2009. Between March of 2008 and February of 2009 the electricity consumed at Klein Constantia was calculated to be 513 425 kWh. This value was therefore chosen as the benchmark figure for electricity consumption at Klein Constantia.

3.5.2 Diesel

The farms diesel is bought in bulk quantities, of around 5000 litres, four to five times a year. Records are kept of these purchases and, as a result of this, the diesel usage for the farm could be determined.

According the farm's purchase records, the total diesel bought in the 12 months between March 2009 and February 2010 was 22 807 litres. There was an 8.5% decrease in consumption, as a result of reduced tilling operations, during the first half of the following year (2010/2011). However, due to a lack of records for the rest of the year, the more complete 2009/2010 figures were used.

Energy total for diesel usage:

The gross energy value of diesel is 46 MJ/kg, which translates into 10.62 kWh/litre (NPL, 2011). Assuming a total of 22 807 litres of diesel consumed:

22 807 x 10.62 = 242 210 kWh of diesel energy consumed per annum.

3.5.2 Total energy consumed annually

When the approximate annual energy consumptions of electricity and diesel were added together, the total reached was 755 635.3 kWh. This value served as the benchmark indicator for the amount of renewable energy that would need to be generated in order to replace the majority of the fossil fuel derived energy sources at Klein Constantia. While petrol, LP-gas and other fossil-fuel-based products were in use on the farm, in small quantities, they fall outside of the scope of this study and were therefore not considered as part of the energy target.

3.6. Energy resources

In order to develop estimates of the renewable energy resources available, a study was made of the weather and hydrological data collected from the Klein Constantia site, along with records from NASA and the South African Weather Service. A number of local renewable-energy companies were also approached in order to ascertain what methods and sources they used when developing energy estimates for sites within Cape Town. Based on the information acquired, estimates were then determined for the renewable energy potential of each of the various technologies in question. The process by which these estimates were attained is dealt with in further detail in the following sub-chapters.

3.6.1 Solar PV

In order to determine the solar data for the site, three sources were considered. These were MLT Drives, NASA and the farm's collected solar data. The MLT drives estimates were based on a combination of satellite and ground based data, while the collected data came from two small weather stations located on the farm itself.

National Aeronautics and Space Administration (NASA):

NASA's online weather data was consulted and provided the following estimates, based on the co-ordinates of Klein Constantia (NASA, 2012):

5.40 kWh/m^2/day – Annual average (Global horizontal)
5.79 kWh/m^2/day – For tilted surface at 34 degrees to the horizontal

MLT Drives results:

MLT Drives is a well-known Cape Town based renewable energy company, specialising in the design and construction of inverters. They were able to provide useful information regarding how they sized prospective client's Solar-PV systems based on the location of the site and the size of the load. The programmer who designed the company's 'System-sizer' software, Josch Thilo (2012), was also consulted regarding the data he used to generate their solar power estimates. In response, the following values were forwarded as the their initial basic estimates of solar irradiation in Cape Town (Thilo, 2012):

5.43 kWh/m^2/day (Global horizontal)
6.55 kWh/ m^2/day (With panel tilt of 34 degrees)

Klein Constantia weather station data:

Hourly surface-tilt measurements of direct and diffuse irradiation had been taken at two small weather stations located on the farm since 2006. The first weather station (Perdeblok) was unable to provide complete results due to significant periods of in-operation. The second station (Delivery Gate) was, however, able to provide continuous solar data for the three years from 2009 through to 2012. The irradiation data from this station was downloaded and inserted into a spreadsheet in order to calculate the site's daily solar potential.

This resulted in the following values across the three year time period:

Weather station 1 (Delivery Gate):	5.622 kWh/day (2011-2012)
	5.811 kWh/day (2010-2011)
	6.121 kWh/day (2009-2010)
Average over the 3 years =	5.85 kWh/day

Determining the final energy yield:

Upon further consultation with MLT Drives, it was determined that the initial equation used by the company to convert from the horizontal to the tilted surface values was very simplistic and meant purely as a guide. This explained, to large extent, the discrepancy found between their values and those of NASA and the farm's weather station. For this reason, the latter two sources were averaged in order to get a final estimate of the solar resource available on a latitude-tilted surface. This resulted in an expected average annual solar potential of 5.82 kWh/day for the Klein Constantia farm.

Assuming a PV-system efficiency of 13.5%, the resultant electrical energy potential of the farm's solar resource was therefore assumed to be:

$5.82 \times 13.5\% = 0.79$ kWh/m^2/day

Another way that the expected energy yield could be determined was through the addition of the rated energy yields of each of the PV-panels in the system. Using the panel's rated peak power output, along with an assumed 5.5 hours of peak sunlight per day, the annual expected energy yield could be calculated. This method was used to determine the energy yields for the financial calculations in chapter four.

3.6.2 Solar-water-heaters (SWH)

The specific energy savings that a standard SWH would achieve is dependent on a number of factors including the solar resource, the profile of water use, the system size and the number of users. In order to determine a national average for the energy savings of SWHs in South Africa, the South African Bureau of Standards (SABS) carried out controlled tests on a number of different 200 litre SWH-systems in 2009. They found that the energy savings per SWH averaged at around 5.67 kWh per day (Eskom, 2010).

While the specific energy savings that would be achieved at Klein Constantia could differ from this value, it nonetheless served as a useful indicator of the savings likely to be achieved. Based on the SABS estimate, therefore, the annual electricity savings were expected to total 2070 kWh per system for Klein Constantia. As explained in more detail in chapter 4, it was determined that the farm would require a maximum of 11 SHWs to cover its hot water requirements. This resulted in a total anticipated energy saving of 22765 kWh per annum, which was taken forward into the financial calculations.

3.6.3 Wind

Records of the hourly wind measurements, taken at the two weather stations located on the farm, were made available. The anemometers at these stations were, however, located only two metres off the ground. The data acquired was, therefore, of little use for the wind-power calculations. This was due to the fact that wind speeds increase significantly with elevation off the ground. Turbulence and gusting would also be an issue at low heights, with local obstacles in the wind path preventing the laminar flow of wind through the anemometers. As a result of these factors, the farms collected wind-data was not considered when determining the site's wind-potential.

Due to the lack of suitable site-specific data, therefore, a more generalised approach was taken. Were wind to be strongly considered in the farms future energy plans, a more comprehensive study would need to be undertaken to determine the farms specific wind potential.

In 2009, a study was conducted into the wind power potential of the South African Breweries headquarters in Newlands (Brosius, 2009). It was found that the measured data, collected from the site over a two-month period, correlated well with the airport's weather-station data. Based on these results, the author was able to use the airport's data for his further calculations relating to the brewery site.

Klein Constantia is located 8.6 km southwest of the Brewery site; which could potentially result in significant differences in their wind patterns. Both sites are, however, in similar positions in relation to the mountain slope. They are also located at similar distances from the airport. As a result of these two factors, the two sites were assumed to share similar wind characteristics. The airport's weather data was therefore used to develop wind estimates for the Klein Constantia site.

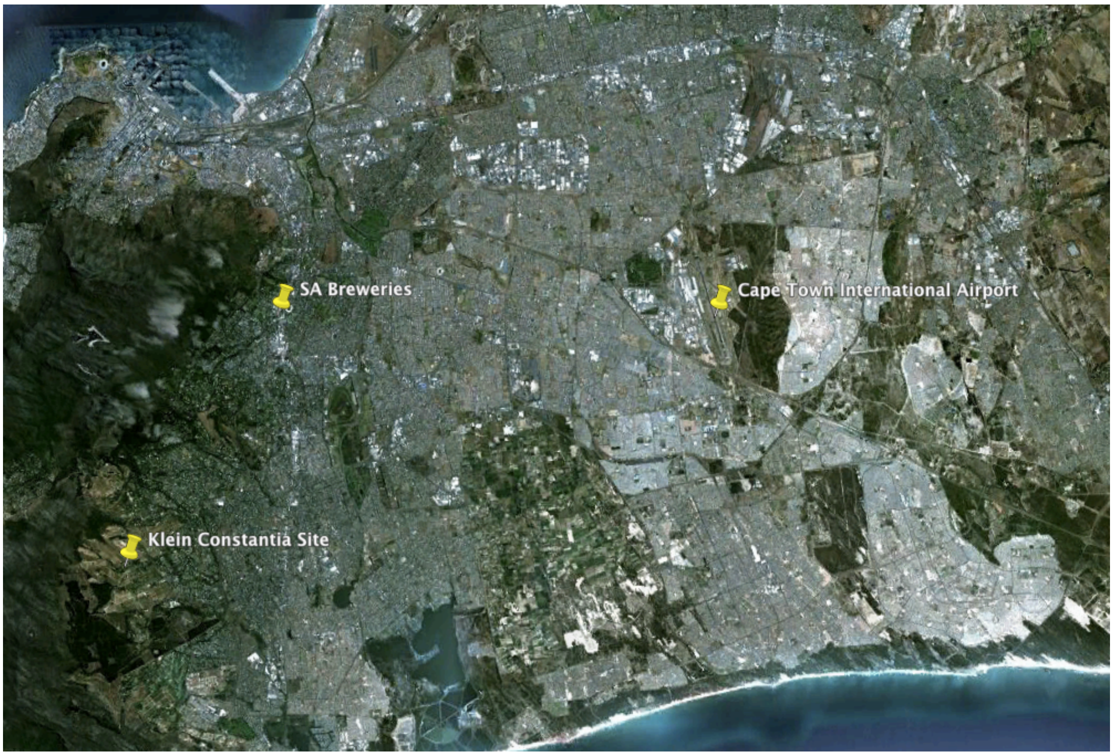


Figure 13: Klein Constantia and the brewery relative to the airport and mountain (Google, 2012)

The values for average wind speeds at Cape Town International Airport (CTIA) were sourced from the South African National Weather Service (SANWS). Results were obtained for two heights, 10m and 18m. For the duration of the study, these values were assumed to represent the anticipated wind potential at Klein Constantia farm.

Table 1: Average wind speeds at the CTIA.

Height above ground (m)	Average wind speed (m/s)
10	5.1
18	5.8

Determining the energy yield

The rule-of-thumb formula for determining the annual energy production from a wind-turbine, based on the average wind speed and rotor diameter, is as follows (Smith, 2008):

Energy output (kWh) = (0.01328) x (blade diameter (ft))^2 x (ave. wind speed (mph))^3

With this formula in mind, a locally based manufacturer of small-wind turbines, namely Kestrel Wind Power, was approached in order to determine the range of sizes available for small-wind in South Africa. They sent through the product specifications of their four largest turbines. These ranged in size from 600W through to 3kW. Assuming an average wind speed of 5.1 m/s across the two smaller turbines and 5.8m/s across the two larger turbines, the following estimates for annual energy production were calculated from the aforementioned formula (Kestrel, 2012):

Table 2: Energy generated according to the turbine size for Kestrel Turbines.

Turbine Model	Rotor Diameter (m)	Annual Energy produced (kWh)
E160i (600W)	1.6	543.07
E230i (800W)	2.3	1122.21
E300i (1000W)	3	1909.24
E400i (3200W)	4	3394.21

Kestrel, as part of their product specifications, also provided an estimate of the annual energy output of their various models, according to the average wind speeds. These graphical estimates of annual energy production, based on average wind speeds, were noted and the results were as follows:

Table 3: Kestrel Wind power's estimation of the expected energy generation (Kestrel, 2011).

Turbine Model	Manufacturers Estimate of energy production (kWh)
E160i (600W)	750
E230i (800W)	1400
E300i (1000W)	2300
E400i (3200W)	3800

The manufacturer's estimates were roughly 30% more than the calculated results. Taking the average of these two sources, the resultant estimates used for the Klein Constantia site were as follows.

Table 4: Average of the two estimates for wind power potential at KC.

Turbine Model	Average of the two sources (kWh/annum)
E160i (600W)	646.5
E230i (800W)	1261
E300i (1000W)	2104.5
E400i (3200W)	3597.11

3.6.4 Biomass

As part of an interview conducted with the wine-maker Stiaan Cloete (2012), the various biomass resources of the farm were assessed. Based on this interview, it was determined that the primary biomass resource available to the farm was grape pomace, a waste product of the winemaking process. The following information was gathered in order to determine the annual pomace production of the farm:

- The farm has 87 hectares of land under vine, of which 20% (or 17.4 h) is currently not in use, leaving 69.6 hectares of vineyards in current use.
- The vines currently consist of 80% white and 20% red varietals.
- The vines are planted at a density of 4000 per hectare and produce, on average, 1.2kg of shoots and leaves per vine per year.
- Between 5.5 and 6 tons of grapes are produced from each hectare.
- For the white wines: 250kg of pomace is produced from the winemaking process for every ton of grapes used.
- For the red wines: 350-400kg of pomace is produced from every ton of grapes used.

Table 5: Summary of Klein Constantia's pomace production levels (Cloete, 2012).

Type:	Hectares under vine	Total Pomace produced (Tons)
Red wine	13.92	26.796
White wine	55.68	76.56
Total	**69.6**	**103.356**

Determining the energy yield:

In order to determine an estimate for the amount of biogas energy that could be generated, two avenues were explored. The first involved using feedstock-energy calculations to determine an estimate, while the second involved approaching a local bio-energy company to determine what they anticipated the energy yield to be.

Calculations based estimate:

Depending on the source, location and the grape-varietal, the expected methane gas production from grape pomace can range from as low as 160 m^3 through to 470 m^3 per ton of pomace (AGREnergy, 2011; Johansson, 2012). It was also ascertained that grape pomace by itself, due to its acidic nature, would not be ideal as the only feedstock for a digester (Araldie et al, 2009). For this reason, a small amount of human and kitchen waste was added to the calculations in order to create a more PH-balanced feedstock, which would be more suitable for digestion. It was assumed that these two waste products could be relatively easily sourced from the farm itself.

Based on these additions, the following assumptions and energy values were used in order to determine an estimate for the energy potential of the feedstock:

- With the additional feedstock included, an average methane production value of 300 m^3 per ton of feedstock (both grape and other waste) was assumed.
- The energy content of biogas, assuming a 97% methane content, was considered to be 9.67 kWh per cubic metre (BalticBiogasbus, 2009).
- A conversion efficiency of 33% was assumed for the generator (Johansson, 2012).
- Human and kitchen waste was assumed to total 1.5kg/person/day for 20 people living and working on the farm.

Table 6: Summary of KC's calculated biogas potential based on the above assumptions.

Feedstock used:	Annual total (Tons)	Methane (m3)	Energy content (kWh)	Electricity produced (MWh)
Pomace, kitchen and human waste	113.95	34185	330568.95	109.1

Agama Energy estimate:

Local bio-digester manufacturers, Agama Energy, were contacted with a view to estimating the amount of energy that might be produced from the grape pomace waste.

Based on the information available, Agama estimated that the grape pomace and a combination of the farm's human and kitchen waste could produce close to 100m^3 of biogas per day (Gets, 2011). Rather than using a specific value for the biogas potential of grape pomace, the company used a more general food value for their calculations. According to their energy statistics, this would translate into around 240kWh of electricity per day, or 87.6 MWh per year.

Final biomass energy yield estimate:

The resultant estimates from the above two methods were averaged in order to determine the final estimate for the farm's biogas potential. This resulted in an anticipated annual electricity yield of 98.35 MWh from the farms biomass resource.

3.6.5 Hydro

The farm's hydropower potential was assessed for two possible systems. The first was a system that would provide a predictable amount of power all year round. The second was one that would take advantage of the increased flow-rates during the winter months.

3.6.5.1 All-year-round system

An assessment of the micro-hydro potential of the farm was conducted on the 9th of March 2012. The intention was to measure the flow rates of the streams during the driest time of the year in order to determine the base minimum flow-rates from which to work.

There are two primary streams that flow through the farm, each fed by a number of tributaries. The larger of the two streams (Stream A) is located in the South-western half of the estate, while the second stream (Stream B) flows close to the North-easterly border of the farm.

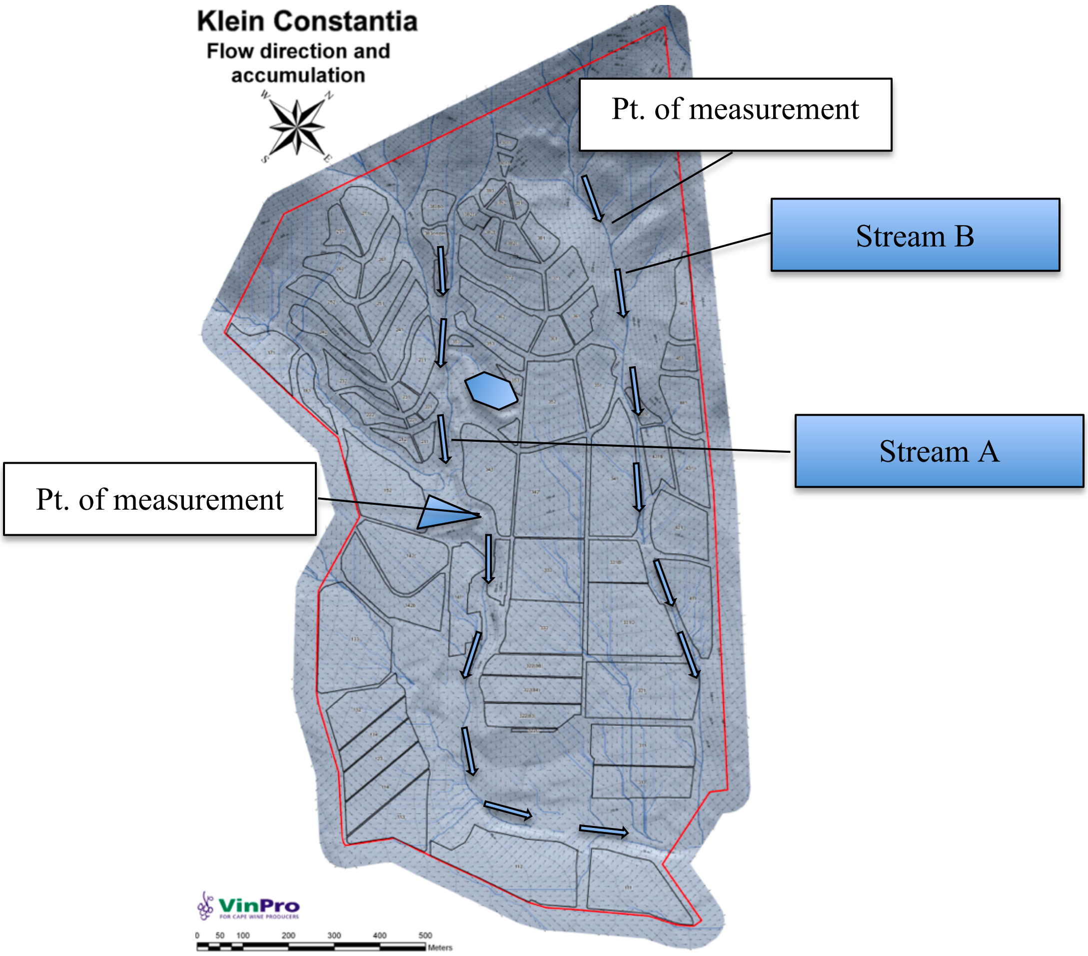


Figure 14: The locations of the two streams that flow through the farm.

The flow-rate of each of these streams was measured at the points shown in Figure 14 above. Stream A was measured at a relatively lower altitude due to the presence of the two dams. The measurements were taken using a bucket and timer; and the results were as follows:

Stream A flow-rate = 3.35 litres/second
Stream B flow rate = 0.7 litres/second

Determining the energy yield:

When determining the potential energy yield from the streams, it was important to note that, for environmental reasons, only a portion of the minimum stream flow-rate would be able to be used for a potential hydropower system. This would be to ensure that sufficient water was always flowing along the streambed, thereby preventing damage to the stream's ecology.

Based on the flow rates measured, the power that could be generated from each of these rivers was determined through the use of the following equation (Lombard, 2011):

$$P_{pot} = \eta_{sys} . \rho_{w} . g . h_{g} . Q_{pipe} \tag{3.1}$$

Where:

P_{pot} = potential power generated (W)

η_{sys} = Overall system efficiency (including the pipes, turbine and the generator)

ρ_w = The density of the water (998.2 kg/m3 at 20˚ (Lombard, 2011))

h_g = The available head (in metres)

g = The gravitational constant (9.812)

Q_{pipe} = The flow-rate (m^3/second)

A number of temporary assumptions were made, regarding the flow-rates and siting of the systems, and are described in the following two subsections. While these were based upon the measurements and site-inspections carried out on the farm, it was considered feasible that, upon the completion of a more comprehensive site-analysis, these values could change.

Stream A:

The following assumptions were made:

- Flow rate separated off for hydro-power system = 2.5 litres/second
- Head = 80m (taken from the level of lowest dam through to eastern corner of the farm)
- Overall system efficiency = 70% (Downey, 2012).

This resulted in a continuous expected electrical power output of 1.37 kW. Assuming a capacity factor of 90%, the resultant annual expected electricity yield was calculated to be 10 812 kWh.

Stream B:

The following assumptions were made:

- Flow rate separated off for hydro-power system = 0.4 litres/second
- Head = 190m (taken from the point of measurement through to eastern corner of the farm)
- Overall system efficiency = 70% (Downey, 2012).

This resulted in a continuous expected electrical power output of 0.52 kW. Assuming a capacity factor of 90%, the resultant annual expected electricity yield was calculated to be 4108 kWh.

Total potential energy yield:

Based on the these two calculations, and assuming that both rivers would be used for energy generation, the total electrical energy that could potentially be generated from the two streams was considered to be 14 920 kWh per annum.

3.6.5.2 Winter system

Due to the fact that the vast majority of Klein Constantia's rainfall is received between the months of May and October, a winter-based system was also considered as part of the micro-hydro analysis.

While there was little hydrological data available for either of the streams, an idea of the expected winter-flow was gathered through discussions held with the wine-maker and other staff on the farm. According to the staff, both streams developed significantly higher flow-rates during the winter season. Stream A, in particular, was known to increase markedly in flow-rate when compared with its summer-low. It was also ascertained that the farm only received 800mm of rain during 2011, compared with an average of around 1600mm. This would no doubt have contributed to the particularly low flow-rates observed when the initial measurements were taken in March 2012.

Aside from the discussions held with the staff, two further sets of measurements were taken in order to better estimate the expected winter flow-rates of the two streams. The first measurements were taken in April, a few days after the passing of Cape Town's first significant cold-front for 2012. The second measurements were taken in mid May, after two further cold-fronts had passed over the city. At the two points of measurement the stream-flow had separated into a number of parallel channels and waterfalls. The splitting up of the flow in this manner allowed for the continued use of the bucket and timer method for determining the flow-rate.

April the 9th:	May the 18th:
Stream A – 12 litres/second	Stream A – 25 litres/second
Stream B – 4.3 litres/second	Stream B – 10.5 litres/second

Based on these two measurements, and considering that the farms wettest months were usually considered to occur between June and September, it was assumed that the two streams would likely continue to increase in flow-rate as the winter progressed. It was also noted that once the irrigation dams were full, the flow-rate of stream A would further increase. As a result of these factors, the anticipated flow-rates that would be available for a winter-based micro-hydro system were assumed to be the following:

Stream A: 20 litres/second Stream B: 8 litres/second

Determining energy yield of the winter-system:

Based on the above winter flow-rates, and similar positioning of the systems, estimates of the potential energy yields could be calculated. It was assumed that the winter-system would only operate from the 1st of June to the 31st October, with the increased energy yields over this period making up for the reductions in operating time.

Stream A:

The following assumptions were made:

- Flow rate separated off for hydro-power system = 20 litres/second.
- Head = 80m (taken from the level of lowest dam through to eastern corner of the farm).
- Overall system efficiency = 70% (Downey, 2012).

These resulted in an expected continuous electrical power output of 10.9 kW for the five-month period. Assuming a capacity factor of 90%, the resultant annual electricity yield was estimated to be 35,5 MWh.

Stream B:

The following assumptions were made:

- Flow rate separated off for hydro-power system = 8 litres/second
- Head = 190m (taken from the point of measurement through to eastern corner of the farm)
- System efficiency = 70% (Downey, 2012)

These resulted in a continuous expected electrical power output of 10.4 kW for the five-month period. Assuming a capacity factor of 90%, the resultant annual electricity yield was estimated to be 33.7 MWh.

Total potential energy yield:

If both streams were to be used for energy generation, the combined estimate for the energy that could be generated from the winter system would total 69.3 MWh per annum.

Table 6.5: The expected energy yields taken forward to the financial calculations.

Solar PV 100m^2 (kWh/annum)	Micro-Hydro (kWh/annum)	Biogas (kWh/annum)	Wind per turbine (kWh/annum)	SWHs 11 units (kWh/annum)
28105	69317	98350	3597	22765

Chapter 4 – Design factors and parameters

In this chapter the various design factors and parameters that led to the final three scenarios are introduced and explored. Following these, the resultant decisions and limitations are summarised, along with the rankings of the various technologies in terms of their favourability. A variety of factors, both qualitative and quantitative, were considered. These ranged from financial and resource based parameters through to aesthetics, operations and maintenance.

4.1 Cost

As would be the case for almost all projects of this nature, cost was considered likely to play a vital role in the farm's decision-making process with respect to renewable energy. The lower the costs of energy-generation, the higher the returns on investment for the farm, and the more inclined they would be to invest.

This factor was especially relevant in the context of the increased levels of financial pressure that have been felt by South African wine producers over the last decade. These pressures have been due, in part, to increased competition from rapidly expanding 'new-world' producers, along with various changes in the local regulatory and legislative environment (Ewert, 2008). As a result, the local wine-industry has experienced significant reductions in earnings in recent years; with profitability in 2012 reported to be at its lowest level in 8 years (Agritv, 2012). Although the extent to which KC was affected by these pressures was unknown, it was still considered of high importance to keep potential costs to a minimum.

4.1.1 Data acquisition

In order to determine the costs of each of the technologies, a number of local manufacturers were approached with a view to attaining quotes for the various products that they supplied.

It was requested that they give as accurate a quote as possible for the complete purchase and installation of their products, including the equipment required for connection to the grid. It must be noted however that, due to the fact that comprehensive site analyses were not undertaken, the quotes could only serve as approximate values for the actual costs. There was the potential that, upon closer inspection of the farm, other unforeseen site-specific costs might need to have been added to the initial quotes.

Solar PV:

Three companies were approached in order to attain quotes for the purchase and installation of a grid tied solar-PV system. These companies were MLT Drives, KG Electric and Solaire-Direct.

Each company was asked to provide a quote for the complete purchase and installation of a 100m^2 system. They were also asked to provide an estimate of the maintenance and labour costs over the life span of the systems.

Table 7: Summary of the quotes received for a 100m^2 solar-PV system.

Company:	Cost estimate (Excl. Vat)
KG Electronic	R 430,000
MLT Drives	R 387,877
Solaire-Direct	R 425,000

Regarding maintenance and yearly costs, all three companies claimed that their systems needed very little maintenance other than the periodic cleaning of the panels. Significant warranties were also on offer for all of the systems. In the case of MLT Drives, for example, the panels came with a 25-year warranty. Taking these factors into consideration, the yearly maintenance costs were considered unlikely to be more than R2000 per year. This figure was reached by combining a monthly-fee for cleaning and an annual fee for general maintenance, as laid out below:

- Once monthly cleaning of panels (R100 x 12)
- Once yearly general maintenance of system (R800)

While the MLT Drives quote was more detailed than the other two, in order to attain a more conservative pricing estimate, the KG electronic quote was used for the financial calculations. They specified that their system would produce close to 14 kW during peak sunlight hours. They also anticipated around 5.5 hours of peak sunlight per day for Cape Town. This would translate into just over 28 MWh per year, which was in line with the calculated potential of the farm, as referred to in the site-analysis.

Solar water heaters (SWH):

Four solar water heater suppliers were approached with a view to attaining quotes for a 200-litre high-pressure indirect system. They were asked to include all installation costs and the relevant rebates on offer from Eskom at the time. The companies approached were Solartech, Aquasol, SolarMax and Greentech.

Table 8: Summary of quotes received for the 200 litre SWHs.

Company:	Type and size:	Cost (Excl. vat)	Expected life-span:
Aquasol	200l Flat-plate	R 11,945	10 years
Solartech	180l Vacuum-tube	R 14,184	15 years
SolarMAX	200l Flat-plate	R 13,207	12 years
Greentech	200l Vacuum-tube	R 15,789	10 years

Based on discussions held with the various companies' representatives, the maintenance costs for the SWHs were expected to be very low over their designed life spans. Warranties of up to 12 years were on offer for a couple of the systems, with the standard offer being a 5 to 10 year warranty.

With this in mind, the maintenance costs were estimated to average R150 per year. This was intended to cover any plumbing and maintenance needs that may arise in the period of time between the end of the warranty-periods and the anticipated lifespans of the systems.

All four SWHs differed in their designs, warranties and specific performance characteristics, resulting in difficulties when comparing them with one another. In the end, however, the higher priced flat-plate system, offered by SolarMax, was chosen for use in the financial calculations to follow. While the vacuum-tube systems may have delivered higher energy returns, the flat-plate systems were both locally manufactured and offered increased durability along with fewer maintenance requirements. Given Cape Town's favourable solar resources, they were also considered likely to provide sufficient hot water for the needs of the farm's occupants.

Wind:

Two local wind energy companies were approached, namely Kestrel Wind Power (KWP) and Earthpower Energy Solutions (EES). KWP produced their turbines locally, while EES made use of imported products. It was requested that their quotes include the purchase of the turbines, towers, installation and the grid connections.

Table 9: Summary of the quotes received from EES.

Turbine type/model	Cost (Excl. Vat)
ZH1.5 KW	R 56 938
ZH2KW	R 62 567
ZH3KW	R 75 708

Table 10: Summary of the quotes received from KWP.

Turbine Type/model	Cost (Excl. Vat)
E160i (600W)	40 000
E300i (1000W)	55 000
E400i (3200W)	120 000

As can be seen from the above tables, there were significant price differences between the two companies. However, due to the possibility of differing levels of quality and performance from one manufacturer to the next, it was decided to use the more expensive Kestrel models during the financial calculations.

As a result of this, the turbine system chosen for the financial calculations to follow was the E400i at a cost of R120 000. The reason for its choice was that the turbine offered the highest energy returns relative to the required capital investment. Kestrel claimed a life span of 20 years for the E400i and also predicted maintenance and labour costs to total 20% of the initial purchase price over the lifespan of the product. The anticipated maintenance mainly consisted of bearing changes every eight years along with periodic servicing of the moving parts (Karpy, 2012).

Biomass:

Of the five technology options available, biogas had the highest levels of cost uncertainty. This was due in part to the difficulty in attaining accurate quotes and figures without an in-depth site inspection and feedstock analysis. There were also no suppliers that supplied all the equipment required. These factors, coupled with the lack of real-life examples of similar systems in the Western Cape, all contributed to the technology's higher cost uncertainty. Agama Energy, however, did provide the following basic quotes for the purchase and installation of two different types of digesters. The first was a large brick-built standard digester, while the second was a relatively new modular design made up of six smaller plastic digesters, called Biogas Pro digesters. Agama also supplied a basic estimate of the costs for the electrical equipment (R400k), which they would usually source separately. Due to the high levels of cost uncertainty, an additional R80,000 was added to both quotes in order to ensure that a conservative capital cost estimate was attained and to allow for some unforeseen expenses.

Table 11: Summary of the quotes received from Agama Energy.

Digester type:	Cost per unit:	24 kW Generator, installation and grid connection	Total Cost (Excl. Vat)
20-day retention digester (35m3)	R 500 000	R 480 000	R 980 000
Biogas Pro digesters (x 6 units)	R 36 000	R 480 000	R 700 000

According to Agama energy, the anticipated operational and maintenance costs of the two systems were as follows:

Standard large digester ($35m^3$) -
- 7-15% of the initial capital costs per year without electricity generation.
- 15-20% of the initial capital including electricity generation system and grid connection.

Biogas Pro digesters (x 6) -
- Daily labour cost of R100 for the feeding and general maintenance of the digesters.
- Assumed 3% of initial capital costs per year for the electrical system O&M *(The additional R80k was subtracted from the capital costs for this calculation due to the fact that Agama was not aware of its inclusion when they provided their O&M estimates).*

In developing the cost-estimates for the previous technologies, the more expensive options were generally chosen in order to determine conservative cost-values for the technologies. In the case of biogas, however, the significantly less expensive Biogas Pro digesters were chosen above the standard brick-constructed digesters. This was due to their efficient, inexpensive and simple design; along with their modular construction, which allowed for future expansion of the system.

As a result of these factors, therefore, it was chosen to use the newer, more efficient technology for the calculations under the assumption that the large-digester design did not provide sufficient benefits to warrant the significant differences in pricing.

Hydro:

Most of the hydropower companies approached specialised in the construction of larger power systems than the ones considered for this project. Two useful sources, however, were found and were able to assist in determining a cost estimate for the micro-hydro systems in question.

The first was a project undertaken between 2008 and 2010 by a master's student at Stellenbosch University (Lombard, 2011). He designed and project managed the construction of a 10kW micro-hydro plant near the town of Porteville, in the Western Cape.

The second source consulted was Mr Pat Downey, owner of Vortex Hydro Systems (VHS). His company specialised in the design and sale of micro-hydro systems in and around South Africa. They, however, did not provide the required construction services and were therefore unable to supply an over-all cost for the design and installation of the systems. As a result of this, the site-analysis and construction costs incurred during Lombard's project were added to the quote supplied by VHS in order to determine a more accurate cost estimate for the systems. These proposed additional charges were also forwarded to VHS who, based on their previous experience with hydropower constructions, deemed them to be suitable.

Based on these two sources, and assuming the use of the winter-system, the following estimates of cost were finally determined:

Table 12: Summary of the cost estimates for the micro-hydro systems.

Source/company:	System size:	Head:	Total cost	O&M costs per annum	Life-span
Lombard, A	10 kW	79m	135 609	349	20 years
Vortex Hydro	10kW	80m	165 220	1000	20 years
Vortex Hydro	11kW	190m	168 390	1000	20 years

As can be seen in the above table, the costs of the Vortex Hydro systems were between twenty and thirty percent higher than those of Lombard's. This was attributed to a combination of inflation and the system design costs, which had been omitted from his final project costs. It was therefore chosen to use the Vortex Hydro Systems quotes in the financial analysis. The costs of the systems for Stream A and B were combined to produce an over-all cost for the farm's entire micro-hydro generation.

Table 13: Summary of the final cost estimate for the combined micro-hydro system.

Supplier:	Combined System size:	Heads:	Total cost (Excl. vat)	O&M costs (per annum)	Life-span
Vortex Hydro Systems	21kW	190 & 80m	R 333,610	R 2000	20 years

4.1.2 Financial calculations

A number of different financial calculations were used to determine the feasibility of the various technologies in question. These are explained in more detail in the following sub-sections:

Pay-back period (PP):

This calculation was used to determine the number of years that would be required to payback the initial capital investment, from the savings accrued, as a result of the installation of a particular RE-technology. This was a simple method by which to compare the various projects, with the assumption that projects with the shortest payback periods were the more viable investments. The formula used to determine the payback period was as follows (VBM, 2011):

$$PP = \frac{IC}{AS - AM} \tag{4.1}$$

Where:
PP = Payback period (in years)
IC = Initial capital investment (ZAR)
AS = Annual savings accrued (ZAR)
AM = Estimate of annual operations and maintenance costs (ZAR)

While the payback period was a useful indicator of projects' feasibility, it did have a couple of important limitations worth considering. Firstly, the PP calculations failed to include the time-value of money. Secondly, they did not factor in benefits that would occur after the payback period, which could often comprise a large portion of the financial incentive. As an initial indicator, however, the calculation proved to be useful.

Net-present value (NPV):

This tool allowed for the projects to be analysed with respect to the time-value of money. Essentially, a project's NPV is the sum of the present-day values of all the cash flows (both in and out) expected over a project's lifetime. In so doing one is able to determine whether a project is a wise financial investment or not. It is generally regarded that an NPV of above zero indicates a suitable investment, while an NPV of below zero is considered an unwise investment. An NPV of zero would neither gain nor lose money for the investor (GT, 2011).

The formula used to determine the NPVs of the projects was as follows (Finance formulas, 2012):

$$NPV = -C_0 + \sum_{i=1}^{T} \frac{C_i}{(1+r)^i} \tag{4.2}$$

Where:
NPV = Net present value (ZAR)
C_o = Initial capital investment (ZAR)

T = Time period (Years)
C = Cash flow (ZAR)
r = Discount rate (%)

One limitation of the NPV calculations, in the context of this study, was that they did not take non-financial benefits into account. These were very relevant to a project's over-all feasibility and needed to be considered along with financial indicators such as the NPV. Another limitation experienced was that NPV calculations were very sensitive to changes in discount rate and inflation, and were thus open to a certain degree of uncertainty based on minor changes to these parameters.

Internal rate of return (IRR):

This financial tool, also known as the discounted cash flow rate of return, was used to calculate and compare the profitability of various investments (Investopedia, 2012).

The IRR of an investment is calculated by making the sum of the NPV's of all the cash flows equal to zero. The higher the IRR, the more profitable the project will be. It was also desirable for the value of the IRR to exceed the interest rate returns that would have been otherwise generated from the initial capital outlay.

The formula used to calculate the IRRs of the RE-investments was as follows:

$$-C_0 + \sum_{i=1}^{T} \frac{C_i}{(1+IRR)^i} = 0 \tag{4.3}$$

Where:
C_0 = Initial capital investment (ZAR)
C = Cash flows (ZAR)
IRR = Internal rate of return (%)
T = Time (Years)

Energy cost (EC):

Finally, the total costs of electricity generation (in Rands per kWh) were calculated so as to compare the costs of the renewable-energies with the cost of standard grid electricity. Technologies that provided a cheaper overall cost of electricity would naturally be favoured above the more expensive ones.

The formula used to determine the energy-costs was as follows:

$$EC = \frac{TLCC}{TE} \tag{4.4}$$

Where:
EC = The final cost of the generated energy (ZAR/kWh)
$TLCC$ = The total life-cycle costs of the project (ZAR)
TE = The total electricity generated over the life-time of the project (kWh)

4.1.3 Results of the financial analysis

Based on the information received from the various suppliers, and the calculations and assumptions made regarding costs, the following financial feasibility results were determined:

Payback period (PP)

The payback-period calculation was used to develop a basic idea of the time that it would take to pay-off the initial capital investments. The results are displayed in the figure below:

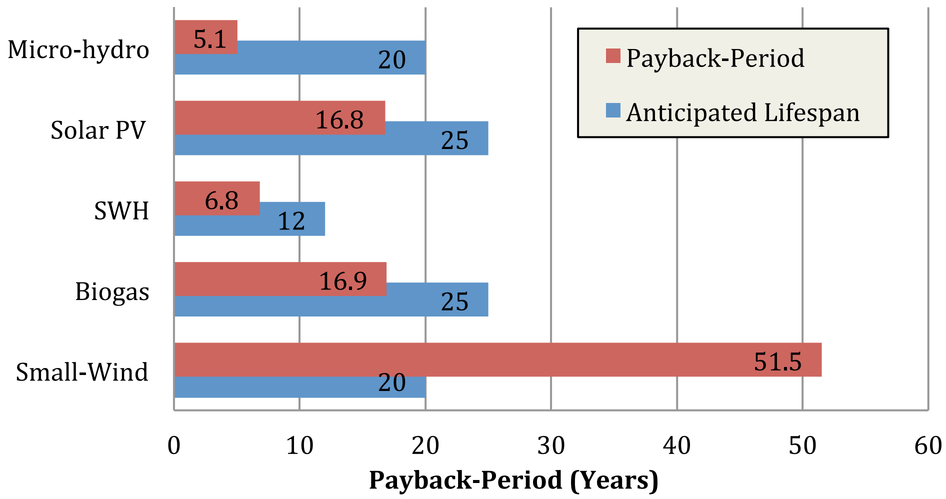


Figure 15: Comparison of payback-periods of the various RE-technology options

As can be seen in figure 15, the calculated payback-periods ranged from close to five years, in case of Micro-hydro, through to over fifty years in the case of small-wind. Taking the anticipated life spans of the technologies into account, only small-wind had a PP that exceeded its intended life span. Based on these initial calculations, therefore, small-wind was considered to be significantly less feasible than the other four technologies.

While the four remaining technologies had more reasonable payback-periods, it is important to note that, in many business scenarios, PPs of more than five years would often be considered to be financially unfeasible due to the significant capital outlays required. In the case of the wine-industry, however, there are numerous other benefits associated with the use of RE that go beyond direct monetary savings. These benefits, along with the energy-cost savings achieved, could potentially combine to make a project with a higher PP more feasible to prospective investors.

Net Present Value (NPV)

The NPVs of the cash flows, over the designed life spans of the various technologies, were calculated. The prime-interest rate of 9%, at the time of the study, was used for the discount rate in all the calculations (StatsSA, 2012). While many commercial businesses would have preferred to use a higher rate, this would have been due their need to accrue higher financial benefits from their investments. As mentioned earlier, in the case of Klein Constantia, the majority of the benefits associated with the installation of renewable-energy would lie outside of the realm of direct monetary returns. These benefits, many of which would have been difficult to quantify, would include new marketing potential, increased access to international markets and the numerous ethical factors associated with reducing the farm's carbon-footprint. The financial analyses were therefore used to determine if the investments lost or gained money overall, but did not factor in an assumed minimum level of profitability.

It was assumed that the operations and maintenance costs would increase, over the life span of the projects, according to the CPI inflation rate at the time of this study. An inflation rate of 6.1% was therefore assumed throughout (StatsSA, 2012). With regard to the annual energy savings, the initial calculations were conducted under the conservative assumption that Eskom electricity prices would also rise according to this inflation rate.

The results obtained were as follows:

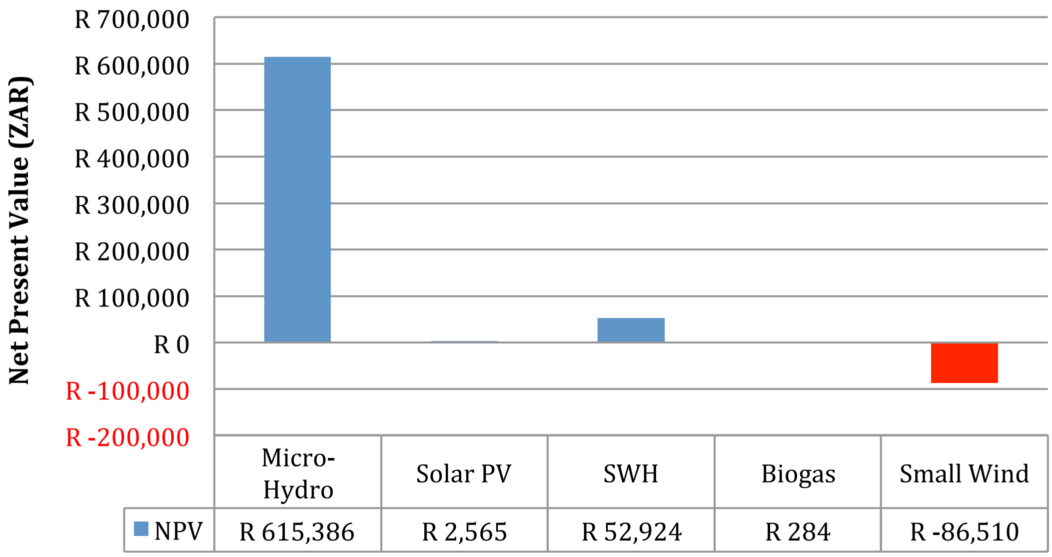
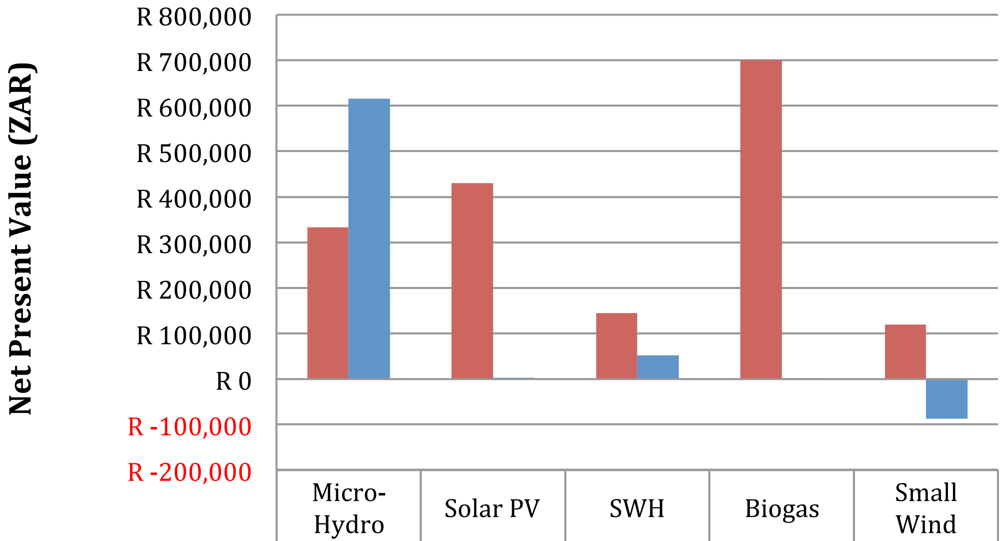


Figure 16: The NPVs of the various RE-technology options

The results, displayed in the above figure, indicated positive returns-on-investment for all the technologies, other than small-wind. These returns ranged from as little as R284, in the case of biogas, through to more than R600 000, in the case of micro-hydro. Small-wind, on the other hand, was anticipated to return a significant loss on investment.

A useful method, by which the technologies could be compared with one another, was to display the calculated NPVs alongside the initial capital investments. This allowed for a better visual comparison of the returns, as they were displayed in the context of the capital required to the achieve them.



	Micro-Hydro	Solar PV	SWH	Biogas	Small Wind
Initial capital	R 333,610	R 430,000	R 145,277	R 700,000	R 120,000
Project's NPV	R 615,386	R 2,565	R 51,998	R 284	R -86,510

Figure 17: Project NPVs compared with their initial capital requirements

From the above figure, it was clear that micro-hydro presented the largest over-all return on investment when compared with the initial capital costs, returning profits of almost double the initial investment. The second most profitable investment was SWHs, followed by solar-PV and biogas. The significant losses shown by wind, in relation to its required capital, further demonstrated the technology's unfeasibility.

Internal Rate of Return (IRR):

In order to further quantify the comparative financial performances of the various technologies, the IRRs were calculated for each of the RE-projects. The results of these calculations were then compared with the discount rate of 9%.

While IRRs of above zero would have indicated a positive return on investment, if the growth-rates were below that of inflation, the investments would have lost money in real terms. If the returns happened to be above inflation but below the discount rate, it would have made more financial sense to leave the money in the bank rather than to invest it. IRRs equal to or close to the discount rate would indicate investments that neither lost nor gained money. In these cases the secondary benefits would contribute to determining if the investments were worthwhile or not. Finally, IRRs of above the discount rate would indicate investments that produced real financial growth.

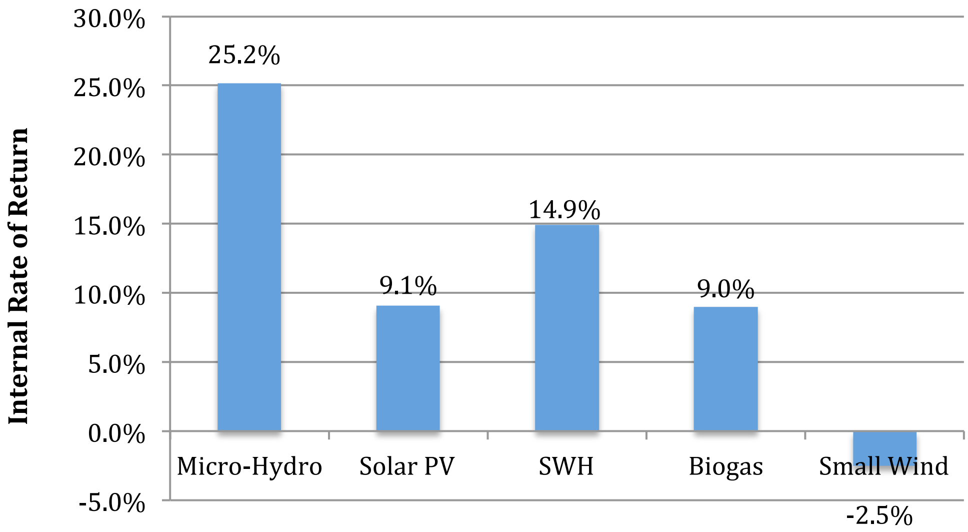


Figure 18: The anticipated Internal Rates of Return for the RE-projects

As can be seen in the figure above, the IRRs of the micro-hydro and SWH systems indicated relatively strong investments, when compared with the other technologies. Solar-PV and biogas were both considered to provide neither positive nor negative gains, while small-wind indicated a loss in value.

Sensitivity:

As referred to earlier in the chapter, the NPV and IRR calculations were very sensitive to the assumed energy costs and to the discount rate used. This was particularly relevant to the cost of electricity, which had been increasing at a rate of well above inflation for a few years prior to the study, and was expected to continue to increase at a similar rate in the years to follow (Lombard, 2011; Eskom, 2012). As a result of this, the initial calculated investment growth-rates were considered to be relatively conservative from the perspective of electricity cost savings.

In order to better grasp the implications of minor variance in these two factors, the following tables were drawn up:

Variance in electricity price:

Table 14: NPV sensitivity to increases in the cost of electricity above the CPI inflation-rate.

NPV	At inflation (6.1%)	1% above inflation	2% above inflation	3% above inflation
Micro-Hydro	R 615,386	R 699,146	R 792,258	R 896,662
Solar PV	R 2,565	R 52,525	R 109,853	R 175,748
SWH	R 52,924	R 63,692	R 75,138	R 87,305
Biogas	R 284	R 175,113	R 375,726	R 606,317
Small-Wind	-R 86,510	-R 82,164	-R 77,319	-R 71,914

Table 15: IRR sensitivity to increases in the cost of electricity above the CPI inflation-rate.

IRR	At inflation (6.1%)	1% above inflation	2% above inflation	3% above inflation
Micro-Hydro	25.2%	26.2%	27.2%	28.2%
Solar PV	9.1%	10.1%	11.1%	12.1%
SWH	14.9%	15.9%	16.8%	17.8%
Biogas	9.0%	11.0%	12.8%	14.4%
Small-Wind	-2.5%	-1.3%	-0.1%	1.1%

As seen in the above two tables, even minor changes to the inflation-rate of electricity would result in significant increases in returns. This was particularly evident in the case of biogas, which saw its NPV rise from R284 through to over R600 000 when the electricity price inflation was raised by only 3%. Wind, while eventually demonstrating a slight positive return, continued to be financially unfeasible even at the higher rates of inflation. It was also interesting to note that, due to its high energy yield and long lifespan, biogas quickly became more profitable than Solar-PV, even when the increase was as little as one percent.

Variance in discount rate:

Table 16: NPV sensitivity to changes in the discount rate.

NPV	DR of 8%	DR of 9%	DR of 10%	DR of 11%
Micro-Hydro	R 704,702	R 615,386	R 536,852	R 467,573
Solar PV	R 52,457	R 2,565	R -40,124	R -76,822
SWH	R 64,646	R 52,924	R 42,142	R 32,208
Biogas	R 81,055	R 284	R -68,826	R -128,236
Small-Wind	R -83,358	R -86,510	R -89,282	R -91,726

Varying the discount rate, as seen in the table above, demonstrated the degree to which the chosen-rate could affect the financial outlook of the projects. While decreasing the rate resulted in increased profits, of particular note was the sharp decline in profits seen as the rate was increased. An increase of only 1% would result in three of the five projects becoming financially unfeasible. The farm's eventual choice in discount rate would therefore need to be carefully considered, taking account of both the financial and non-financial benefits, so as to arrive at the most favourable compromise.

Final Cost of Energy:

To complete the financial analysis, the estimated life-cycle-costs of the various projects were totalled up. It was decided to include the cost of capital (CoC) in the final calculations, under the assumption that the farm would need to borrow the money required for the investments. The total costs were then divided by the total electrical energy expected to be generated by the technologies across their life spans. From this, the anticipated final cost of energy was determined for each technology.

Table 17: Summary of the energy data calculations with respect the total real costs of energy.

	Wind	Solar PV	SWH	Micro-hydro	Biogas
Energy yield per annum (kWh)	3597	28105	22770	69317	98350
Lifetime Energy yield (kWh)	71942	702625	273240	1386334	2458750
TLCC Excluding cost of capital (Coc) ZAR	144000	480000	165077	373610	2077500
TLCC (Including cost of capital) ZAR	282960	1132400	257400	760240	3139700
Total energy cost (Excl. CoC) c/kWh	200.2	68.3	60.4	26.9	84.5
Total energy cost (Incl. CoC) c/kWh	393.3	161.2	94.2	54.8	127.7

As seen in the figure below, when the cost of capital was not included in the total cost estimates, a number of the technologies were determined to be less expensive than the Eskom tariffs at the time.

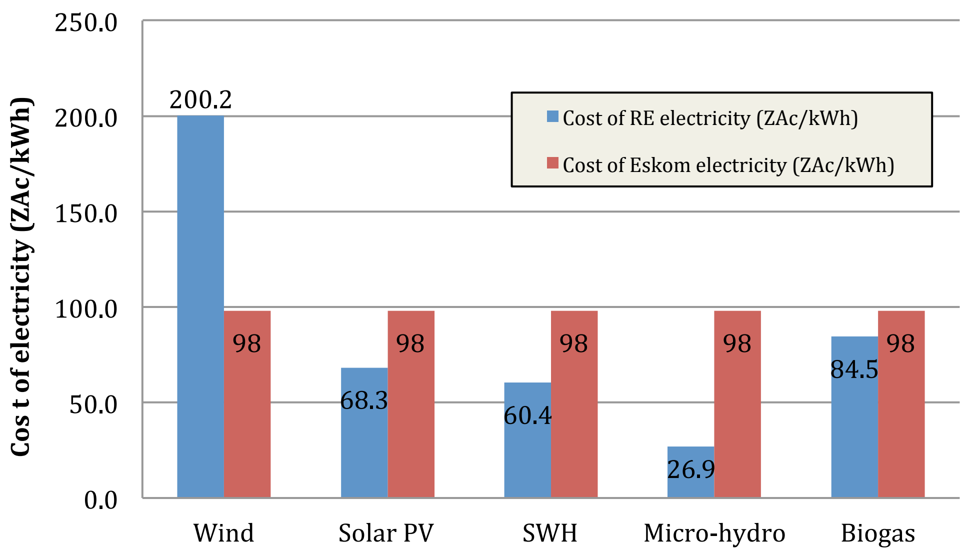


Figure 19: The COE compared with the farm's tariff (excluding the cost of capital).

While these costs seemed low, it was important to note that the quotes reflected a net-metering system. The fact that net-metering was assumed meant that the substantial costs associated with energy-storage could be avoided, thus making the project significantly more viable from a financial perspective. Were storage to have been included, the costs of energy for the various technologies would have been significantly higher. In the case of the Solar PV system, for example, the final cost of energy would have almost doubled (MLT, 2012).

When the cost of capital was included, the calculated total energy costs rose to the following, considerably higher, values:

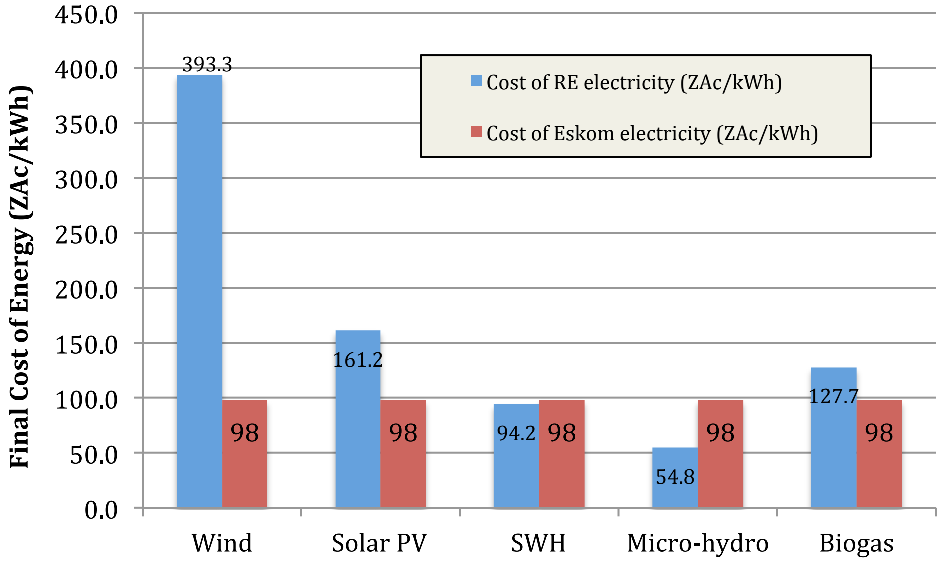


Figure 20: The COE compared with the farm's tariff (including the cost of capital).

As seen in the above figure, there was a general increase in the cost of energy across the board, particularly in the case of small-wind and solar-PV. While the cost of biogas also rose, it was not as sharp as the other technologies due to a large portion of its life-cycle cost being attributed to O&M.

The costs of solar-PV and biogas increased well beyond the farm's average electricity tariff, while SWHs and micro-hydro remained less expensive, if only slightly less in the case of SWHs. It was noted, however, that the majority of the farm's hot water consumption fell under the more expensive "domestic use" tariff. The ordinary charge to the farm would, therefore, have been higher than the 'average tariff used in the above table.

4.1.4 Financial feasibility conclusions

Based on the results of the various feasibility calculations, the following ranking system was constructed in order to better compare the viability of the various technologies. Each technology was ranked according to its financial feasibility with the most viable receiving a ranking of one, and the least viable a ranking of five.

Table 18: Ranking system for the financial performance of the various technologies.

Technology	Payback period	NPV	IRR	Final energy cost	Total
Micro-Hydro	1	1	1	1	4
Small-wind	5	5	5	5	20
Biogas	4	4	4	3	15
Solar-PV	3	3	3	4	13
SWH	2	2	2	2	8

Discussion:

From table 17, it was clear that two technologies, namely solar-water heaters and micro-hydro, stood out as being the most financially viable. Both offered payback periods of less than 10 years; and both provided positive returns on investment. Solar PV and biogas had longer payback periods and lower returns. However, when taking their numerous secondary benefits into account, they were also considered to be financially feasible for the purposes of this study.

While micro-hydro offered the highest financial returns, only two South African based suppliers could be found for the system sizes in question. This resulted in a relatively higher level of uncertainty with regards to the expected cost of the systems, as only one quote was received. Lombard (2011) demonstrated that a suitable micro-hydro system could potentially be built within the quoted cost parameters. The realisation, however, of a similar project at Klein Constantia would rely heavily upon the accuracy of the quote received from Vortex Hydro Systems.

As the more established of the five technologies, solar-water-heaters appeared to offer the most predictable and secure investment. This was due to the proven nature of the technology in the Western Cape, along with the significant number of established suppliers available in the area.

After SWH and micro-hydro, the next most viable option was solar-PV, which generated a slight profit and had a payback period of close to 17 years. While the return on investment was minimal and payback period was lengthy, the technology would be able to supply a significant amount of energy and could potentially be scaled up with relative ease to meet a rise in demand. There were also numerous suppliers within the Western Cape who specialised in projects of this nature.

Following closely behind solar-PV was the biogas system. While this technology did not offer a significant return on investment, it was important to note that it would not lose money either. In addition to this, assuming increases in the cost of the electricity in the years to follow, biogas would become substantially more profitable according to the financial calculations, overtaking solar PV in a short space of time. These factors, combined with the presence of local suppliers and the numerous benefits associated with the use of renewable energy, allowed for the consideration of biogas as a feasible alternative to grid electricity in this study.

Small-wind ranked last amongst the various technologies on offer and was clearly an expensive form of renewable energy in this case study. This result, however, rested upon the estimated wind potential of the site and the cost of the turbines. Following a more comprehensive study into the site's wind potential and the costs of suitable quality turbines, the overall cost of the energy generated could potentially be reduced. In the interim, however, wind was considered to be unviable from a financial perspective at Klein Constantia.

4.2 Space and resource limitations

All of the renewable energy technologies in question faced space and resource limitations of some kind or another. These limitations would naturally affect the extent of the implementation potential of the technologies within the Klein Constantia estate. Some of these limitations are explored in the following sub-chapters.

Micro-hydro:

Practical limitations:

- the flow-rates of the streams.
- the heads available.
- the availability of suitable sites for the diversion weirs, power-houses and penstock piping.

It was apparent that the primary practical limitations, in the case of micro-hydro, were the flow-rates of the two streams and the positioning of weirs and pump houses. Different heads could be achieved by moving the diversion weirs and power-houses further up or down the mountainside. For the sake of the energy calculations, however, preliminary sights were chosen for these structures. They were chosen based upon the site inspections carried out and the locations of the dams.

While a more comprehensive site-analysis may have revealed more favourable locations, such a study fell outside of the scope of this project. It was therefore decided to carry the preliminary site choices through to the design phase, along with the relevant energy-generation potentials associated with each of them.

Solar-water-heaters:

Practical limitations:

- the availability of suitable sun-facing roof-space for mounting.
- the hot-water requirements of the farm.

The primary limitation in the case of SWHs was the amount of hot water required by the farm. If more heaters were installed than required, their savings would have ceased to be of value. Based on discussions with the farm manager, it was established that the Klein Constantia Estate had a total of seven houses within the property. These ranged from guest and worker's cottages through to the large main farmhouse. The winery also made use of three electric geysers as part of its operations.

Assuming the use of one 200-litre SWH per standard household, two for the main farmhouse and three for the winery: a total of 11 SWHs was therefore considered sufficient to meet the farm's hot-water requirements.

Regarding the need for suitable roof-space for the mounting of the SWHs, it was anticipated that there would be more than sufficient space to accommodate all the required heaters. While this roof-space might need to be shared with panels from the PV-system, the SWHs would likely take preference over the PV-panels due to their higher financial returns. Nonetheless, they only take up a portion of the roof-space and there was also the added option of storing the water-tanks within the roofs, thereby freeing up further space.

Solar-PV:

Practical limitations:

- the availability of unobstructed land/roof-space for mounting of the panels.
- the availability of low-shade, high radiation sites.

The primary practical limitation to the installation of a PV-system, as mentioned above, would be the substantial amounts of space required for the mounting of the panels. It would be essential that the panels faced towards the sun for as much of the day as possible. This meant that the roof-panels would generally only be located on the northerly sides of the roofs, thereby halving the eligible roof-space available.

Figure 21: View of the farm buildings with the potential solar-PV sites shown in blue.

In order to attain an estimate for the amount of eligible roof-space available the areas, highlighted in blue in figure 21, were measured using a scaled photograph of the farm. This resulted in a total roof-space estimate of 2113 m^2. Of this, the large barns and the winery together accounted for 1600 m^2 of the total, with the combination of the smaller buildings making up the rest.

Aside from roof-space, there were numerous other options available for freestanding PV-panel configurations. These ranged from upright 5-panel steel frames through to simple ground-mounted systems. All of these options, however, required the availability of sufficient sun-facing and unobstructed land that lay outside of the floodplains of the streams. In the case of Klein Constantia, almost all of the land that met these criteria was already under vine. While in time it may become more feasible to replace sections of the vineyards with solar-arrays, for this study it was considered unlikely that the owners of the farm would consider this to be a viable option.

Two further locations that were considered to be important possible options for the siting of the panels were the irrigation dams, located in the upper section of the farm. While the mounting of PV-panels has historically almost always been land based, in recent years a number of successful floating systems have been developed around the world (Sustainable business, 2008). Klein Constantia's two dams have a combined area of approximately 3200 m^2 and, if a suitable floating framework was sourced, could potentially generate a significant amount of power.

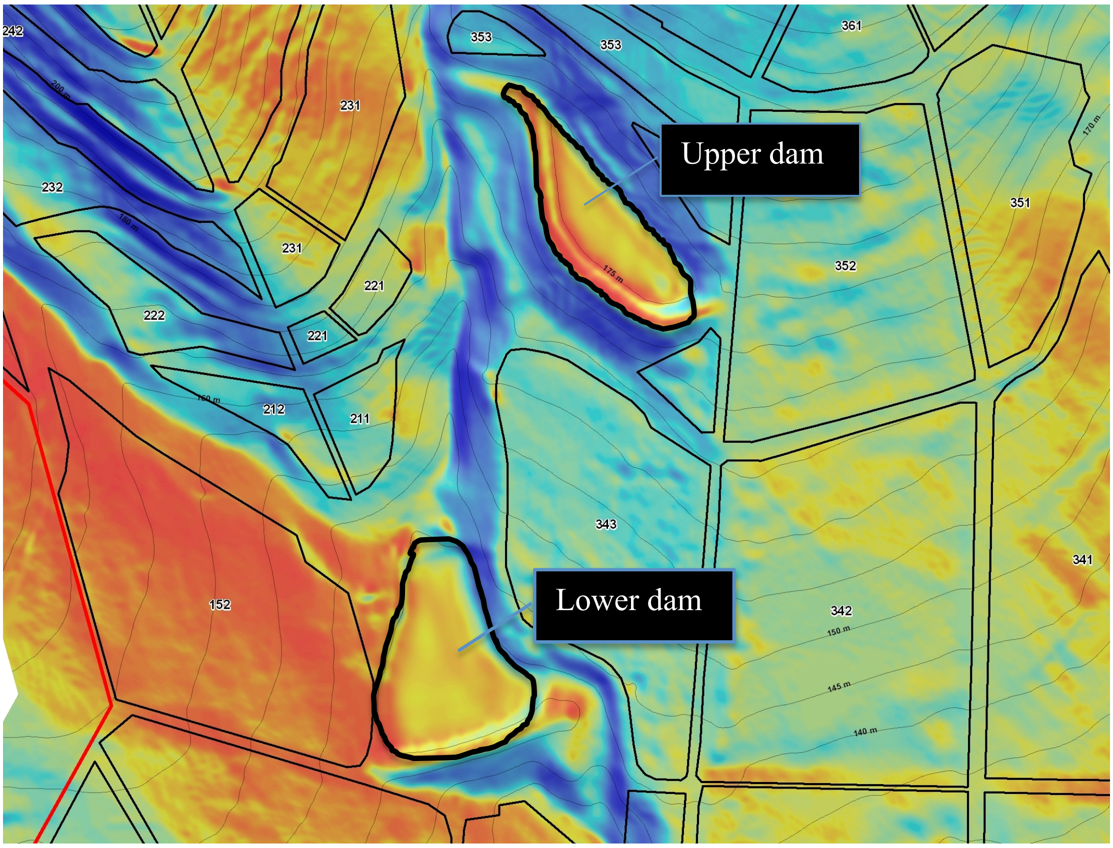


Figure 22: Aerial view of the two dams showing the solar radiation levels.

While the dams were located relatively far from the rest of the farm buildings, they did provide a large surface area to work with and were shown to receive high levels of radiation, from figure 22. The suitability of these sites could also be further improved by mounting the panels on a latitude-tilted frame.

The floating systems currently in use around the world use relatively simple constructions, which primarily involve the mounting of the PV-panels onto floating pontoons or frames (Inhabitat, 2008). At the time of the study, it appeared that no South African companies offered this service, thereby increasing the likely cost of acquiring such a system.

Biogas:

Practical limitations:
- the availability of biomass for feedstock.
- the availability of a suitable location to house the digesters and other equipment.

The primary practical limitation with respect to biogas was the availability of feedstock for the digesters. The amount of feedstock available from the farm itself would naturally be limited by the annual grape production. This production is determined by the amount of land under vine, by the choice of cultivars and by the density of their planting. These, along with numerous other viticulture practices, would determine the amount of pomace available for biogas production.

Due to winemaking being the primary function of the farm, it was considered unlikely that these practices would be significantly altered in order to benefit biogas production. Rather, pomace production levels would more likely be affected by quality or business decisions relating to the wines themselves. Increases in biogas potential would, therefore, only be seen as additional co-benefits or disadvantages to these decisions. Another option available to Klein Constantia would be to source further pomace feedstock from neighbouring farms in the Constantia valley. While this could feasibly result in significant increases in the farm’s biogas generation potential, the use of external resources lay outside of the scope of the study and was therefore not considered in this section.

With regards to the housing of the digesters within the Klein Constantia estate, it was desirable that they be located a suitable distance from the various buildings, thoroughfares and places where people congregate. This was primarily due to the odour often associated with the digestion of feedstock (Getz, 2012).

Based on the site inspections carried out on the farm, there were numerous sites that would fit these criteria. These ranged from the open area just below the main irrigation dam through to various potential sites in the northerly and easterly corners of the estate. All of these sites offered a distance of at least 200m from the farm buildings and would be located downwind when the prevailing south-easterly wind was blowing. While there would no-doubt be other factors that would need to be considered when determining a suitable digester site, it was anticipated that, due to the variety of sites available, a suitable location would be found that met all these criteria.

Wind:

Practical limitations:

- the availability of suitable high-wind locations with the desired level of laminar airflow.

The primary practical limitation with respect to wind-power was the availability of suitable sites for the turbines. Accurately determining the locations and extent of these sites would, however, require an in-depth study into the estate's wind potential, which fell outside of the scope of this project. A basic analysis was therefore carried out using the following industry 'rule-of-thumb' criteria:

1. Wind speeds tend to increase towards to the top of gradually sloping hills and ridges making them ideal for turbine sites (Southwest, 2010).
2. To reduce excessive turbulence, avoid locating turbines close to cliffs or very steep inclines (Rhageb, 2012).
3. Turbines should be placed at least three to five rotor diameters apart in the direction perpendicular to the prevailing wind (Rhageb, 2012).
4. The turbines should be mounted at a height of at least 10 metres, plus the length of a turbine blade, above any obstacles within a 150-metre radius (Solacity, 2012).

The figure below indicates the areas that, based on the rule-of-thumb analysis, appeared to best fit the criteria.

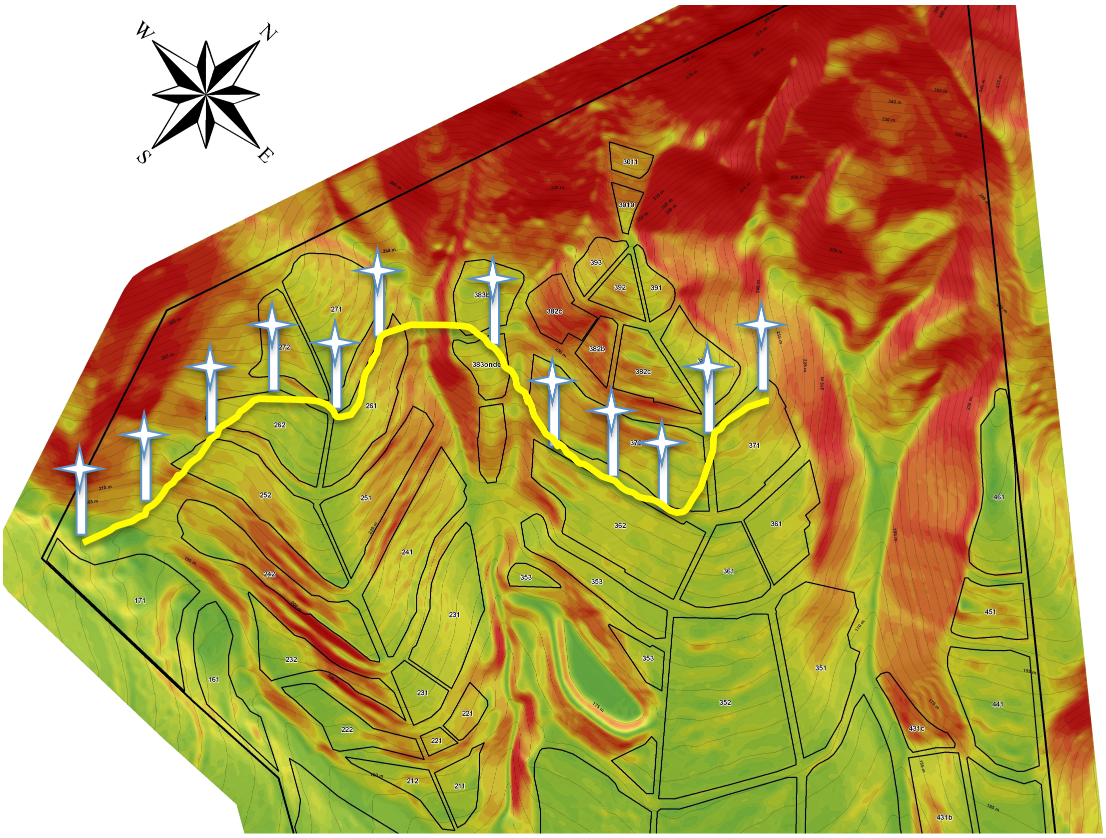


Figure 23: Aerial view of the top half of the farm, showing the gradient of the land and the proposed locations for the wind-turbines.

The proposed sites were all located at an elevation of between 220 to 250 metres, well above surrounding obstacles and sufficiently high to allow for some concentration of the wind resource. The slopes of the various sites ranged from 6 degrees up to around 18 degrees, thereby minimizing the turbulence associated with very steep inclines while still retaining desirable elevation. They were also positioned in a rough line from the south-west to the north-east corner of the farm in order to take advantage of the prevailing south-easterly winds. It was decided that, due to the resultant turbulence and the steep incline of the land, the turbines would not be located directly behind or in front of one-another. Rather, a single line of turbines would roughly follow the contour of the hillside.

According to a topographical map of the farm, the total distance covered by the proposed turbines sites, along the contour of the mountain, was estimated to be approximately 800m. Assuming the use of the 4m-diameter Kestrel turbines, and a separation of 5 rotor-diameters between the turbines, the designated area could house a total of forty 3.2kW turbines.

While a more in-depth study into the farm’s wind potential may have revealed better and more numerous suitable sites for small-wind; for the purposes of this study, the maximum number of turbines able to be practically and efficiently accommodated on the estate was therefore assumed to be forty.

4.3 Reliability of resource

The reliability of each of the renewable resources was of importance from an energy-portfolio design perspective. While this issue had been factored into the annual energy estimates, the level of supply-uncertainty from day to day differed significantly amongst the technologies. The levels of these uncertainties would naturally be reduced when assessed over a longer period of time and would also be of less importance if net metering were assumed. However, if operations such as load matching were to be considered at a future date, the day-to-day reliability of the resources would be of significant importance.

Of the four sources available, namely Wind, Solar, Hydro and Biomass, each had an intrinsic level of uncertainty associated with it. This, when combined with the specific operating mechanisms of the various technologies, allowed for some conclusions to be drawn regarding the day-to-day reliability of the energy sources. These uncertainties and their causes are discussed in further detail in the following sub-sections:

Micro-hydro:

There would be the possibility of drought or flooding effecting the operations of the micro-hydro systems. In the case of flooding, the flood would have to be destructive enough to either break-apart or disable the diversion weir; or the water would have to rise well above the high-water mark to flood the powerhouses. Both of these eventualities, while possible, were considered unlikely to occur.

Drought, on the other hand, would likely have a higher chance of affecting the micro-hydro operations. Reductions in the amount of water entering the system would invariably lead to energy-generation and system-efficiency reductions. While droughts would no doubt occur, it was important to note that the flows separated by the diversion weirs were designed to be well below the anticipated flow-rates of the streams. It was therefore considered likely that the systems would continue to operate even during minor drought periods.

During pro-longed droughts the systems would invariably have to operate at reduced capacity. In general, however, provided that the flow-rates were correctly chosen, the micro-hydro systems were anticipated to provide a reliable source of power.

Solar-Water-Heaters and Solar-PV:

Of the solar-powered technologies, SWHs were considered to be the more reliable of the two. This was due to the fact that SWHs operate under numerous forms of radiation while solar-PV relies primarily on direct-beam radiation. SWHs would therefore continue to operate in cloudy conditions, albeit at a lower efficiency, while PV-panels would experience a higher drop in efficiency, even under light cloud (Energyworks, 2009).

The Western Cape climate is, however, generally very well suited to solar technologies, and both PV and SWHs were considered likely to provide reliable energy performance from day to day. While the winter months would certainly see a reduction in the quantity of energy produced, this reduction would be relatively predictable when compared with regions with more erratic climates. Also, as the majority of the Western Cape's rain would be generated by cold-fronts, the arrival of overcast conditions could be forecast days and sometimes weeks in advance. This might allow the farmer time to put appropriate back-up systems in place, where necessary, and, to a large degree, would eliminate the element of surprise.

Biogas:

Due to the presence of a reliable and predictable supply of feedstock, in the form of grape-pomace, biomass was considered to be one of the more reliable renewable-energy resources available to the farm. While wind, sunshine and stream-flow would all be subject to changes in the weather; the amount of biogas available would be based almost entirely upon the carefully controlled grape production of the farm. This was particularly relevant, in the case of Klein Constantia, as the farm had access to two large irrigation dams which would be able to supplement the farm's rainfall when required, thereby further securing the production levels.

According to the farm manager, droughts in the past had never fully depleted these two dams during his tenure. Changes, therefore, to the amount of pomace available for energy generation would likely be primarily driven by outside factors such as the planting of new varietals or the use of different farming techniques. As these changes would affect the grape production and therefore the volume of wine produced, they would likely be tightly controlled and predictable in nature. In order to make up for changes in supply of pomace, the farm could also potentially source grape-pomace from neighbouring farms as a back-up plan to their regular supply.

Wind:

Of the four sources of renewable energy in question, wind is often considered to be the least reliable within smaller time scales (Rosenbloom, 2005). This is primarily due to the often-unpredictable nature of wind over short periods of time, and to the limited window of wind-quality in which turbines can operate. It is therefore common, and in most cases necessary, to augment the use of wind-power with grid-power, storage or other more reliable renewable resources such as hydro (Chapmen & Barry, 2009). As a result of these factors, wind was considered to be the least reliable resource on a day-to-day basis.

4.4 Aesthetics and public acceptability

The issues of aesthetics and public perception were identified as important factors in the decision-making processes around renewable-energy in the wine-industry. Wine, as a product, is often considered to be synonymous with concepts such as luxury, sophistication and beauty. Technologies that are not perceived to fit into this mould would therefore be less likely to be adopted within the industry. This would particularly relevant to a farm like Klein Constantia, which has to carefully manage its reputation as one of South Africa's oldest and most prestigious wine-estates. These issues, in relation to each of the technologies, are explored in the following sub-chapters.

Micro-hydro:

Historically, installations of large-hydro projects have often been accompanied by public resistance over various issues. These have ranged from the removal and relocation of affected communities, to the flooding of areas of commercial, conservation and sometimes even religious significance (Truchon, 2004). As a result of these issues, large-hydro has often been considered to have a negative public perception (Appleyard, 2011). The same perceptions, however, do not necessarily apply to micro-hydro. If carefully designed and managed, micro-hydro systems have the potential to be both aesthetically acceptable and able to garner positive public reaction. This is due to a number of positive historical and practical characteristics of the technology, some of which are listed below:

- Micro-hydro systems, in the form of water wheels, have been closely associated with agriculture for many hundreds of years.
- Modern systems require only minor diversion weirs or canals without the need to significantly alter the course or appearance of the stream.
- Only a portion of the flow is diverted to ensure that water is always flowing down the stream.
- The technology is relatively silent and unobtrusive.
- The penstock piping can be hidden or buried to remove the negative impact they may have on the aesthetics of the stream course.
- Micro-hydro systems can sometimes be incorporated into existing irrigation pipe networks, reducing the need for new constructions.
- The streams on which they are located are often located on private farm land, thereby reducing the number of affected parties.

While there were many factors that contributed towards making micro-hydro feasible from a public relations and aesthetic perspective; its non-modular and relatively significant construction requirements were still considered likely to increase the chances of complications occurring above some simpler and less-obtrusive technologies.

Solar water heaters:

In the light of South Africa's recent power shortages and rising electricity tariffs, the solar-water-heater industry has experienced significant growth in the Western Cape. Public perceptions of SWHs, when compared with many other RE-technologies, are generally good with most people considering them to be a positive addition to a property (SEIA, 2011). A number of the technology's attributes may contribute to this perception, including:

- The technology operates silently.
- The systems take up a relatively small amount of space when compared with other RE technologies.
- An electric element can be easily incorporated into the system, allowing for dependable back-up power when necessary.
- SWH's can be mounted on the roof of a building, often out of sight of the rest of the property.
- The water tanks can be located inside the roof of the building, allowing for a simpler, less obtrusive and more aesthetically pleasing installations.
- The technology operates very effectively in the Western Cape's climate, thereby fuelling the positive sentiment towards it.

These benefits, along with numerous others, contributed towards SWHs being considered one of the most publically accepted and well-known RE-technologies available. This public acceptance had been further bolstered in recent years by extensive promotion and backing of the technology by the Department of Energy and Eskom.

Solar PV:

PV technology possesses numerous positive attributes, from a public and aesthetic perspective, including the following:

- The systems operate noiselessly and don't have any moving parts.
- Panels can often be conveniently located on unused roof-space, thereby reducing the need for land-use change to accommodate the technology.
- The flat rectangular design of PV-panels allows them to be easily and aesthetically incorporated into the architecture of new and existing buildings.
- PV technology has been used to power many common electronic devices for a number of years already and is therefore well known and generally accepted by the public as a viable and dependable technology.
- PV-systems are modular in construction and can therefore be expanded or reduced in size according to changes in the energy demand.

These positive characteristics led to the technology being considered to have a generally positive public perception. There were, however, a couple of factors that needed to be taken into consideration when comparing solar PV with some of the other RE technologies available.

The first of these was the relatively low energy density of the technology and the resultant high space requirements associated with PV-systems. While roof-surfaces could offer a significant amount of space to work with, when the energy requirements exceeded that which the roof-space could provide, other less-convenient sites would have to be used. Another factor considered, in the context of Klein Constantia, was the age and history of some of the farm's buildings. While there were unlikely to be major issues associated with attaching panels to recently built buildings, it was certainly possible that there would be public and legislative resistance to altering the appearance of some of the more historically significant buildings on the farm, such as the farm house. These buildings, however, represented only a small percentage of the total roof space available on the farm.

Biogas:

Bio-digestion offered an effective means by which to handle much of the farm's organic waste. This was coupled with a number of other positive attributes from a public-opinion perspective. These included:

- The technology operates silently.
- In the context of the amount of energy generated, relatively little space is required to house the digesters.
- The digesters can be buried to reduce their visual impact on the land.
- When digesters make use of animal waste on dairy or chicken farms, they serve to significantly reduce and contain the smell associated with these farms (Mott, 2011).
- The digesters have few site requirements, and can therefore be located in relatively hidden and remote parts of the farm if necessary.
- Bio-digesters are already in effective use on numerous farms around the country including the well-know wine farm, Backsberg Estate.

These factors all contributed towards the technology being considered viable from a public opinion and aesthetic perspective.

The primary factors counting against the adoption of the technology, in the context of this sub-chapter, were the smell and hygiene issues associated with digestion and the storage of the feedstock. Although the smell of bio-digesters could be significantly contained if correctly designed and managed, public opinion would nonetheless likely favour other RE-technologies over biogas production on the basis of this perception (Mott, 2011).

Wind:

Of all the technologies in question wind has likely garnered the most public attention, both positive and negative, within the Western Cape in the years prior to this study. Some of the more positively perceived attributes of the technology were as follows:

- The technology operates with some noise, but is still relatively quiet when compared with alternatives such as diesel generators and pumps
- Wind-power was in use all around the world and is one of the fastest growing RE-technologies at present.
- Windmills have been used to power water-pumps on South African farms for many decades; and in so doing have established a historical connection between the wind-power and agriculture.
- The Western Cape has been identified as an area generally suited to wind-power, with projects such as the Darling Wind Farm helping to establish the technology in the public mind-set.

These positive attributes, along with numerous others, have contributed to wind being considered an important part of South Africa's energy future. There are, however, a number of negative perceptions and attributes of small-wind in particular, which may hamper its adoption:

- Small wind has developed a reputation for generally being unreliable and ineffective when compared with large-scale wind and other technologies (Sagrillo, 2008).
- Based on the numerous interviews, correspondence and phone-conversations conducted with the various companies and manufacturers in the local RE market, small-wind is generally not seen as efficient, effective or reliable within the Western Cape. In line with this point, almost every party recommended other technologies of theirs above small-wind for energy generation.
- Due to the need for the turbines to be mounted on high-towers at elevated sites, the visual impact of the technology on the surrounding landscape is considered to be significant. The specific impression given off by the presence of the towers could be construed as either negative or positive, depending on the viewer. The impact alone, however, could potentially reduce the chances of the turbines being adopted above other less overt technologies.
- While turbines don’t make a loud noise during operation, they do contain numerous moving parts and therefore produce significantly more noise then technologies like solar PV or SWHs.
- There is a common public perception that wind-turbines have a negative effect on bird-life.

Negative factors aside, the many positive attributes of wind-power will likely see its continued expansion within the Western Cape and other parts of the country. Due to the numerous negative perceptions associated with small-wind, however, it is considered likely that the majority of this expansion will be in the form of large-wind installations. Based on the above discussions, therefore, small wind was seen as the least viable of the RE technologies in question from the perspective of public opinion and aesthetics.

4.5 Operation and maintenance requirements:

While the estimated labour costs for the operation and maintenance, of the various technologies, were accounted for in the financial calculations, these costs did not reflect the additional time that would need to be spent on oversight and monitoring by the farm management.

With this in mind, technologies that required less maintenance and were less labour intensive were considered likely be favoured above others that required a larger degree of oversight. These issues are explored in the following sub-chapters:

Micro-Hydro:

While micro-hydro systems would have little in the way of operational requirements, , there would be a variety of regular maintenance needs to consider as a result of their numerous moving parts. Some of these needs might include (Kumara, 2012):

- Prevention and monitoring of silt and debris build up at the water intake-point.
- Monitoring, maintenance and replacement of the bearings, belts and other moving machinery within the pump house.
- General miscellaneous maintenance requirements related to the exterior constructions (e.g. leaks, weir-repairs, and electrical faults).

The number of miscellaneous maintenance issues that arise would likely be closely aligned to the strength of the fittings; and the quality and skill of the construction team used to build the systems.

Another important factor to consider was that of flood-damage. While most micro-hydro systems are designed to withstand floods, there would still be significant work required to clear debris and silt at the intake-weir after flooding. This issue was, however, not considered to affect Klein Constantia to a large extent.

According to the farm manager, the farm’s two irrigation dams and the generally mild climate of the area had resulted in damaging floods occurring very infrequently. Only one significant flood had been recorded on the farm in the 15 years prior to this study, pointing to a reduced chance of flood damage affecting the proposed micro-hydro systems on a regular basis (Cloete, 2011).

Solar water heaters:

Due to the simple nature of their design along with a general absence of moving parts, solar water heaters were anticipated to require very little maintenance and operation. While there would be the possibility of damage to the glass panels or leaks in the piping, these problems could generally be fixed by a standard plumber and were considered unlikely to arise very often.

Solar PV:

Due primarily, once again, to a lack of moving parts solar-PV systems were considered to have few maintenance or operational needs on a day-to-day basis. Some on-site maintenance, however, would be required from time to time.

The primary anticipated maintenance needs were as follows (EMA, 2011):

- The prevention of shade encroachment
- Periodic cleaning of the panels
- Checking for cracks and damage to the panels and other equipment
- Seasonal adjustments to the panel's angle of tilt (Only applicable in the case of adjustable frames)

The health and performance of PV-systems can often be remotely monitored through a variety of digital interfaces; and it is not considered uncommon for systems to operate problem-free for a number of years (Jakobi & Starkweather, 2010). In general, therefore, the technology was considered to provide reliable service without the need for extensive and regular operations and maintenance.

Biogas:

Of the five technologies in question, biogas generation was considered to have the highest operational and maintenance needs. Along with this, numerous secondary tasks would also emanate from the primary energy generation process. With regards to operation, the following requirements would need to be met on a regular basis (Ghimire, 2008):

- Collection, processing and storage of the feedstock supply.
- Daily feeding of the digesters.
- Preventing the build-up of a scum layer at the top of the digestion chamber.
- Regular monitoring and adjustment of the liquid levels, acidity and gas pressure within the digesters.
- Collection, processing and distribution of the resultant biomass slurry.

While the specific maintenance requirements differed from one design to another, there were a number of common maintenance requirements amongst them. These included (Goodrich, Gustafson, & Hauer, 2003):

- Regular checking for gas leaks.
- Periodic cleaning out of the digesters to remove any unwanted build-up of solid material in the digestion chambers.
- Regular monitoring and cleaning of the slurry outlet.
- Monitoring, repair and replacement of the belts, bearings and other equipment related to the electricity generation.

As a result of the numerous requirements listed above, biogas generation was considered to have significantly higher operational and maintenance needs than the other four RE-technologies. It was of importance to note, however, that most of the required labour would be manual and would not require specialist knowledge. It could also probably be carried out, to a large extent, by the farm's existing work force.

Small-wind:

Compared with biogas, small-wind was anticipated to have relatively few operational and maintenance requirements. There were, however, a number of requirements that would need to be met in order to ensure the reliable operation of the turbines.

The primary operational requirement would be to ensure that the site retained the best possible conditions for the wind-power. This would be achieved primarily through the monitoring and removal of obstructions and excessive plant-growth from the wind-path.

The maintenance needs would primarily relate to the various moving parts within the turbine housing, including (Walford, 2006):

- Regular greasing of the turbine bearings.
- Periodic repair and replacement, when necessary, of the moving parts within the turbine casing.
- Repairs, when necessary, to the turbine blades and towers.
- Monitoring and repairs related to the electrical generation and transmission.

The degree and frequency with which these maintenance requirements would need to be carried out would invariably differ from one manufacturer to another. This would likely be closely related to the quality of the materials and workmanship; and would probably be reflected in the product's cost.

4.5 Environmental impacts:

Although investing in renewable energy is generally perceived to be environmentally friendly, the technologies still have some impact on the environment. The differences between the technologies, in this regard, were considered to have the potential to affect the decisions made regarding which technologies to employ, with lower-impact technologies likely to be favoured above the others.

4.5.1 Carbon-footprint:

An important factor to consider, from an environmental perspective, was the life-cycle carbon analysis of the each of the technologies. While all five were considered renewable, some had been shown to have larger carbon-footprints than others due to the differences in their material and constructional requirements.

The following table lists the CO_2 equivalent emissions of the various technologies per kilowatt-hour of electricity produced (Akella, Saini, & Sharma, 2008).

Table 19: CO_2 emission of the technologies over their anticipated lifespans.

Renewable energy technology	CO_2 emissions over the estimated life-time of the technology (g CO_2/kWh)
Small-hydro	9
Solar-water-heaters	4.2*
Solar-PV	98-167
Biogas	17-27
Small-Wind	7-9**

* Source: (Kalogirou, 2008) ** Source: (Rankine, Chick, & Harrison, 2006)

The actual carbon-footprint of each technology would likely differ from the above values when applied to the specific site-characteristics of Klein Constantia farm. The above table, nonetheless, served as a guide to the GHG-emissions associated with each technology. It was apparent that solar-PV was likely to result in the highest emissions of the five technologies.

Biogas was the second most emissions-intensive technology, however, this was due primarily to the fact that the carbon-required for the planting, fertilizing and collection of the biomass was included in the total. In the Case of Klein Constantia, most of these processes would occur anyway, as part of the normal operations of the wine-farm. The footprint of the digesters themselves would therefore be significantly lower than the above values.

The remaining three technologies resulted in emissions of the below 10 g CO_2/kWh and were therefore considered to be the most favourable from an emissions perspective. It was also useful to note that all five technologies resulted in significantly lower emissions that coal-derived electricity in South Africa, which has been estimated to produce 978 g CO_2/kWh (Zhou, et al., 2009).

4.5.2 Localised impacts:

These refer to the impacts that would be experienced within the vicinity of the various RE-technologies as a result of their implementation. Some of the more common impacts associated with each of the technologies are explored in the following subchapters.

Micro-Hydro:

Of the five technologies, micro-hydro was considered likely to have the largest impact on the local environment. This related primarily to the diversion of a portion of the stream-flow, which would then be directed through the micro-hydro system. There would also be secondary impacts, including erosion and sediment built-up, related to the construction of the diversion weir and the penstock piping. Were these factors not to be taken into account, during the design phase of the systems, they could result in negative effects to the ecology of the area downstream of the diversion weirs. The silt build-up at the weirs could also increase levels of methane emissions due to the concentration of wet decomposing organic matter (Abbasi, 2011).

For these reasons, all micro-hydro projects in South Africa require an Environmental Impact Assessment (EIA) to be carried out before construction may begin. The EIA would also need to be sanctioned by the Department of Environmental Affairs and Development Planning (Lombard, 2011). In these assessments, the various environmental impacts would be considered and, where possible, quantified in order to determine the environmental feasibility of the projects.

While measures such as these would ensure that the environmental impacts of the project are kept within acceptable limits, micro-hydro systems would invariably still retain a higher degree of impact compared with some of the other technologies available to the farm.

Solar water heaters:

Due to the fact that solar-water-heaters are small in size, and are usually located on rooftops, their impact on the local environment was regarded as minimal.

Solar PV:

It was considered likely that there would be very few local environmental impacts associated with the installation of Solar-PV at Klein Constantia. Were farmland or natural bush to be cleared to make way for solar panels, the impact on the environment would invariably increase. This, however, was considered unlikely to occur at Klein Constantia in the short to medium term; and was therefore not seen as significant factor in the context of this study.

Biogas:

The introduction of biogas digesters to a farm is often accompanied by numerous positive local environmental impacts. These range from general reductions in odour and harmful pathogens; through to increases in water quality in the local streams and rivers. These benefits are, however, mostly applicable to farms which keep animals and where manure is used for the digester feedstock. Due to the use of grape pomace rather than manure as the primary feedstock biogas generation at Klein Constantia was expected to have a smaller impact on the local environment. Although, as the grape-pomace would be processed rather than being left to rot, the overall effect to the local environment was still considered to be positive.

Small-wind:

The local environmental impacts associated with small-wind would primarily be related to the moving turbine blades and their effect on the surroundings. Potential impacts could range from the increased noise and visual pollution, through to the risk of bats and birds flying into the turbines (UNDP, 2012).

While proper siting and design of the turbines could significantly reduce these impacts, wind-turbines would nonetheless invariably result in a greater impact to the local environment than some of the other technologies in question.

4.6 Resultant limitations and ratings

Based on the various calculations and discussions, the following conclusions were drawn regarding the incorporation of RE-technologies at Klein Constantia. These provided practical limitations for the scenario designs and also allowed for a ranking system to be drawn up in order to determine the most favourable technologies. The rankings, along with the practical conclusions reached, are summarised in the following two subchapters.

4.6.1 Practical limitations

The following practical limitations and design-parameters were determined for each of the technologies:

Micro-hydro:

The maximum energy generation potential was considered to be that which the two streams could produce given the assumptions made in chapter three regarding the flow rates, locations of the weirs and the siting of the pump houses. It was also assumed that the winter-system would be employed and would operate for five months of the year. With this in mind, the electricity expected to be generated by the micro-hydro systems totalled 69.3 MWh per annum.

Solar-PV:

The maximum space available for solar-PV panels was considered to be the combination of the north facing roof spaces and the surface-areas of the two dams. This totalled approximately 5200m^2.

Of the 5200m^2, the areas available on the roofs of the winery and the barns were considered to be the best options for siting of the panels. Following these, the two dams were seen as the next best options. The least favourable scenario was a decentralised system comprised of a collection of smaller arrays located on the remaining smaller buildings. This was partly due to the added costs associated with a decentralised system, but also to the aesthetic and legislative barriers that may hinder such a design.

It was assumed that the panels would be located on fixed-tilt frames set to South Africa's angle of latitude (34 degrees). It was also assumed that a suitable floating pontoon system could be sourced for the two dams at a reasonable cost that would not far exceed the added costs of a decentralised system.

Based on these assumptions the maximum energy generation potential was determined as follows:

5200m^2 x 0.79 kWh/m^2/day = 4,1 MWh/day = 1 499.4 MWh/annum

The total potentials of each of the three primary site options were as follows:

1. Large roofs (Barn and Winery):

$1600m^2$ x 0.79 $kWh/m^2/day$ = 1264 kWh/day = 461.3 MWh/annum

2. The two dams:

$3200m^2$ x 0.79 $kWh/m^2/day$ = 2528 kWh/day = 922.7 MWh/annum

3. Small roofs (combination of the remaining smaller buildings):

$400m^2$ x 0.79 $kWh/m^2/day$ = 316 kWh/day = 115.3 MWh/annum

Solar-Water-Heaters:

Eleven SWHs were considered sufficient to replace the farm's current group of electric geysers. The installation of further geysers would have to be justified by increased hot-water demand. The maximum electricity savings potential of the technology was, therefore, considered to be:

11 x 2079 kWh savings per annum (Chapter 3.6.2) = 22 869 kWh/annum

Biogas:

The maximum electricity generation potential for biogas was assumed to total 98.35 MWh per annum. This was based on the assumption that only Klein Constantia's grape pomace and waste would be available for use as feedstock. Sourcing extra biomass from neighbouring farms was therefore not considered as an option in this study.

Small-wind:

The number of sites considered to be suitable for small-wind installations were limited to those identified in the chapter 4.2. This resulted in a maximum number of forty 3.2kW turbines, which equated to an energy generation potential of:

40 x 3597.11 kWh/annum = 143.88 MWh/annum

4.6.2 Rankings

The following simple ranking system was applied to the technologies in order to determine the most favourable options according to the chosen design parameters. The specific rankings reached were based on the combination of quantitative and qualitative analyses carried out on each of the technologies in the previous subchapters. As a result of its particular importance to the decision making process, the scores for 'cost' were doubled. The results reached are summarised in the following table.

Table 20: Final ranking system used to compare the various technologies.

Technology	Cost	Reliability of Resource	Aesthetics and Public Acceptability	O&M	Local Environmental effects	GHG-emissions	Total
Micro-Hydro	2	2	3	3	5	3	18
Solar-PV	6	4	2	2	2	5	21
SWH	4	3	1	1	1	1	11
Biogas	8	1	4	5	3	4	25
Small-Wind	10	5	5	4	4	2	30

Based on the total scores from the above table, the final rankings were determined to be (in order from the most to the least favourable):

1. Solar-Water-Heaters
2. Micro-Hydro
3. Solar-PV
4. Biogas
5. Small-Wind

Of all the technologies in question, it was clear that small-wind presented the least favourable RE-investment for Klein Constantia. This coupled with its particularly bad performance in the financial analysis resulted in the decision to not consider small-wind as a viable option for the farm, other than in the theoretical 'maximum energy' scenario. The rest of the technologies, while differing in favourability and feasibility, were considered to be suitable for further exploration.

Chapter 5 – Scenario designs

This chapter outlines three renewable energy scenarios that could be considered for Klein Constantia. In each case, a map of the farm is included, with the proposed locations for the RE-technologies shown in yellow. The overall financial performance of each scenario was also analysed, along with other factors, in order to determine the most favourable option for the farm.

5.1 Maximum Energy

This scenario investigated the maximum amount of renewable energy that could be derived from the farms resources, assuming only the practical limitations discussed in chapter four and the five technologies in question. Cost and feasibility were not considered as design parameters, as the intention was purely to determine the benchmark for the farm's total RE-generation potential.

When the maximum generation potentials of each of the technologies were added together, the results were as follows:

Table 21: Summary of the 'Maximum energy' scenario for Klein Constantia.

Technology:	Units:	Generation per unit:	Total Electricity per annum:
Micro-Hydro	2 systems	35.5 and 33.7 MWh/annum	69.3 MWh
Solar-PV	5311 m^2	0.79 $kWh/m^2/day$	1499.4 MWh
Biogas	6 digesters	40kWh/digester/day	98.35 MWh
Small-Wind	40 turbines	3597.11 kWh/annum	143.88 MWh
SWHs	11 heaters	2070 kWh/annum	23 MWh
Total			**1834 MWh**

Note: the farms annual electricity consumption was 513.425 MWh (from chapter 3).

As seen in the above table, it was determined that the farm could produce more then three times as much electricity as it consumed. In time, as the cost of electricity increases and the cost of RE-technologies decreases, some of the limitations that were applied to this study would likely change. These changes could potentially result in further increases to the farm's energy generating potential. The above figures were however considered to be the maximum generating potentials, given the farm's prescribed limitations at the time of this study.

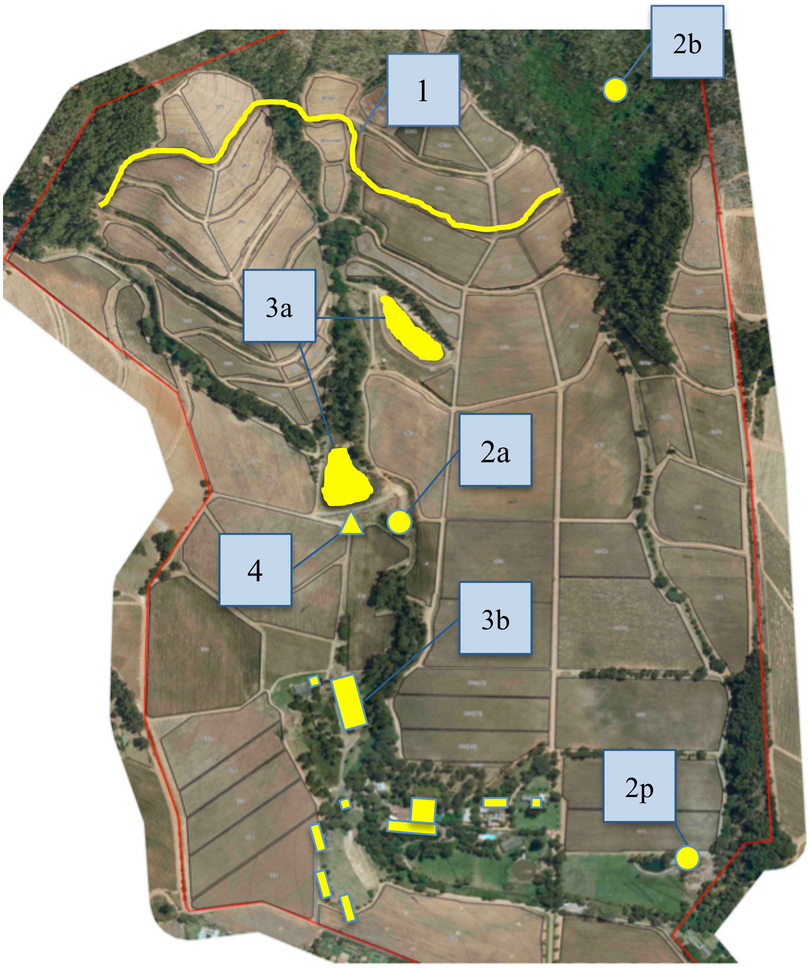


Figure 24: Proposed layout of the 'Maximum energy' scenario at Klein Constantia.

The numbers in figure 24 refer to the proposed sites for the following technologies:
1 – Small Wind
2a – Stream A micro-hydro inlet pipe (using dam as diversion weir)
2b – Stream B micro-hydro diversion weir and inlet pipe
2p – Pump-houses for the two micro-hydro systems
3a – Irrigation dams used as sites for solar-PV
3b – The various farm buildings to be used as sites for PV-panels and SWHs
4 – Bio-digesters and feedstock storage

The various financial calculations were applied to this combined energy-mix in order to attain an overall impression of the scenario's financial performance. The results were as follows:

Table 22: Summary of the financial performance of the 'Maximum energy' scenario.

Capital cost	NPV	IRR	PP	Cost of Energy (Excl. Vat)
R 28,816,187	-R2,655,608	8.10%	18.2 years	R1.52/kWh

As shown in the table above, the 'maximum energy' scenario would require a capital outlay of almost 30 million rand and would take more than 18 years to pay off. In terms of returns, the scenario did not perform well, as evidenced by the negative NPV and the relatively low IRR. Given the amount of the energy generated and the presence of small-wind in the calculations, however, the returns on investment were not as low as initially anticipated. The negative effect that the high-cost of the wind turbines had on the overall financial feasibility was somewhat diminished by the positive gains from the hydro and SWHs, resulting in a final cost of energy that was surprisingly low.

While this ‘Maximum Energy’ scenario was, for a variety of reasons, considered unlikely to be adopted within the short to medium-term, it nonetheless served as a useful indicator of the over-all energy generation potential of the farm.

5.2 Electricity and fuel

This scenario investigated the renewable energy mix that would be required to cover the farm’s electricity and diesel usage. All the design parameters and limitations were taken into account in order to determine the most favourable approach to achieving the energy target.

As referred to in the site-analysis, assuming a one-to-one conversion from the diesel-fuel to electrical-energy, the total annual electrical energy required to replace the farm’s electricity and diesel usage was considered to be 755.64 MWh. While this conversion was inherently simplistic in nature (due to it not accounting for the changes in efficiency between electric and diesel vehicles), the results were nonetheless considered to be interesting and provided a useful estimate of the technology mix that would be required to achieve this energy target.

As a result of the higher levels of uncertainty around the costing of the floating solar-PV system, it was decided to rank biogas ahead of the floating system in terms of favourability. This also allowed the scenario to potentially take advantage of the significant jump in profitability that biogas would yield if the electricity price increased above the inflation rate. The ranking system for the technologies was therefore split up as follows:

1. Micro-hydro
2. SWHs
3. Solar-PV (Large roofs)
4. Biogas
5. Solar-PV (Floating system)
6. Solar-PV (Collection of remaining smaller roofs)
7. Small-wind

Using this, the energy-mix required to meet the combination of the farm’s electricity and diesel usage was determined to be the following:

Table 23: Summary of the ‘Electricity and Diesel’ scenario for Klein Constantia.

Technology:	Units:	Generation per unit:	Total Electricity per annum:
Micro-Hydro	2 systems	35.5 and 33.7 MWh/annum	69.3 MWh
Solar-PV (Large roofs)	1600 m2	0.79 kWh/m^2/day	461.4 MWh
Solar-PV (Dams)	360 m2	0.79 kWh/m^2/day	103.7 MWh
Biogas	6 digesters	40kWh/digester/day	98.35 MWh
SWHs	11 heaters	2070 kWh/annum	23 MWh
Total			**756 MWh**

Note: the farms annual electricity and diesel consumption was 755.655 MWh (from chapter 3).

As seen in the table above, a combination of four different technologies would be required to meet the scenario's energy needs. The Solar-PV system, which would make up the majority of the energy generation, would need to be split between the large roofs and one of the dams, with the roofs housing the majority of the panels. Although the remaining three technologies would account for less than a third of the total energy generation, they were nonetheless considered to be a vital part of the scenario's energy mix. This was due their numerous positive contributions to the overall financial feasibility of the scenario and to the security of the energy supply.

Unlike solar-PV, both the micro-hydro and biogas systems would also be able to operate at night. In the absence of net metering, this factor could be of immense value to the farm as a means by which to reduce the need for costly energy storage systems.

Figure 25: Proposed layout of the 'Electricity and diesel' scenario at Klein Constantia.

The numbers in the above figure refer to the proposed sites for the following:
2a – Stream A micro-hydro inlet pipe (using dam as diversion weir)
2b – Stream B micro-hydro diversion weir and inlet pipe
2p – Pump-houses for the two micro-hydro systems
3a – Irrigation dam used as site for solar-PV
3b – The various farm buildings to be used as sites for PV-panels and SWHs
4 – Bio-digesters and feedstock storage

When the various financial calculations were applied to this scenario, the results were significantly more favourable than the 'Maximum energy' scenario.

Table 24: Summary of the financial performance of the 'Electricity and Diesel' scenario.

Capital cost	NPV	IRR	PP	Cost of Energy (Excl. Vat)
R 9,602,587	R 718,835	9.71%	15.3	R1.30/kWh

As seen in the above table, the initial capital investment reduced to under R10 million, returning a positive NPV and an IRR of above prime. The primary contributor to this positive change in feasibility was the absence of small-wind from the calculations, along with the greater relative contribution of the micro-hydro and SWHs to the overall profitability. It was noted, however, that even a 5% error with regards to purchasing and O&M costs would result in the loss of almost all profits.

Although the payback-period was reduced from 18 to 15 years, it was still considered to be high. The cost of electricity also dropped significantly, however the farm's average tariff was still more than 20% less expensive at the time of the study.

Based on these results, the overall outlook for the scenario was considered to be marginally positive. While it would be expensive and would not yield significant financial returns, neither would it lose money for the farm. This factor, when combined with its numerous secondary benefits, resulted in the scenario being considered potentially feasible. The final decision regarding its feasibility would, however, rest upon a number of other factors, some of which are discussed later in this chapter.

5.3 Electricity only

This scenario investigated the renewable energy mix that would be required to replace only the farm's annual electricity usage. Once again, all the design parameters and limitations were taken into account in order to determine the most favourable approach to achieving the energy target. As discussed in chapter three, the farm's annual electricity usage was assumed to total 513.4 MWh. With this in mind the energy-mix required to meet the target was determined.

Table 25: Summary of the 'Electricity only' scenario for Klein Constantia.

Technology:	Units:	Generation per unit:	Total Electricity per annum:
Micro-Hydro	2 systems	35.5 and 33.7 MWh/annum	69.3 MWh
Solar-PV (large roofs)	1461 m2	0.79 kWh/m^2/day	421.2 MWh
SWHs	11 heaters	2070 kWh/annum	23 MWh
Total			**513 MWh**

Note: the farms annual electricity consumption was 513.425 MWh (from chapter 3).

Due to the reduced energy needs, this scenario's target could be met using just three of the five technologies available. While solar-PV would still produce the bulk of the energy, the entire system would now be able to be housed on the large roofs of the barns and the winery, thereby significantly reducing the levels of pricing uncertainty.

Figure 26: Proposed layout for the 'Electricity only' scenario at Klein Constantia.

Although biogas did not feature in the energy-mix for this scenario, this was primarily due to the assumptions of net-metering and inflation-locked tariff increases. Were one of these assumptions to have been removed, biogas would potentially have been considered more favourable than solar-PV and may have been included in the scenario's energy mix. In line with the scope of this study, however, both of these factors were assumed to be present. Given the relative simplicity of solar-PV, when compared with biogas from an O&M perspective, it was also considered wise to keep the design as simple as possible.

When the financial calculations were applied to the scenario, the results were as follows:

Table 26: Summary of the 'Electricity only' scenario for Klein Constantia.

Capital cost	NPV	IRR	PP	Cost of Energy (Excl. Vat)
R 6,761,187	R 705,779	9.99%	14.7	R1.32/kWh

As seen in the table above, while the capital cost of the project reduced to under R7 million, the NPV remained at a similar level to the 'Electricity and Diesel' scenario. With the removal of the uncertainty surrounding the floating-PV costs, the financial returns were also considered to be significantly more secure.

The payback period, while shorter than the other two scenarios, was still considered to be high. The cost of energy also remained relatively high when compared with the farm's average electricity tariff.

5.4 Discussion

Taking all three scenarios into consideration it was clear that the smaller the overall energy demand, the more feasible the required RE-system would become. While this was most evident from a financial perspective, it was also noted that many of the other parameters and limitations, discussed in chapter four, would be positively affected by a simpler, less-obtrusive design. For example, one of the primary obstacles to the 'Maximum energy' scenario would likely be the significant impact that it would have on the aesthetics of the estate. As a result of this impact, a combination of negative public-perception and legislative restrictions could potentially prevent the adoption of the scenario before the financial implications had even been considered. Due to these and many other factors, the 'Maximum energy' scenario was not considered to be a viable option for the farm, leaving the remaining two scenarios to be assessed.

As mentioned earlier in the chapter, the basic outlook for the 'Electricity and diesel' scenario was considered to be marginally positive. While it returned a small profit and had a lower cost of energy than the first scenario, its overall feasibility rested upon a number of less-secure factors. These included, amongst others, the costing of the technologies, the sourcing of a suitable floating PV-system and the assumption that the electricity generated would be able to cover the farms diesel usage. Ideally, the replacement of the farm's diesel-usage would be achieved by investing in a fleet of electric vehicles that could take the place of the farm's tractors and trucks. This outcome was, however, considered unlikely to occur in the short to medium term due to the cost and technology limitations associated with such a move. There would also be inherent issues with trying to equate the two energy carriers (fuel and electricity) due to the fact that electric motors are significantly more efficient in their use of energy than diesel engines. With this in mind, a more appropriate method for making use of an 'electricity and diesel' scenario would be to use the carbon savings generated by the renewable-energy to offset the carbon-footprint of the diesel fuel by reducing the demand for coal-derived electricity on the grid or by feeding carbon-neutral electricity into the grid. A study such as this would, however, have fallen outside of the project scope and is therefore included in the recommendations for further study.

With these complicating factors in mind, and given its marginal financial performance, it was considered unlikely that the farm owners would view the 'Electricity and diesel' scenario to be feasible, unless they had a specific and compelling reason to do so. An example of such a reason could be if the farm was trying to achieve carbon-neutral status. In this case, however, there might be numerous methods by which this could achieved and the scenario would need to be considered in the light of all these options.

From a financial perspective, the ‘Electricity only’ scenario stood out as the most viable of the three scenarios. While its payback-period was still considered to be lengthy, it was noted that the primary basis of such an investment would unlikely centre on the desire for swift financial returns. The nature of viticulture also often necessitates the need for longer-term investments due to the time taken for new-plantings to mature and bare fruit.

Given the assumptions made, the financial returns of the ‘Electricity only’ scenario were anticipated to be small but relatively secure, with an IRR of just under 10%. The cost of energy also reduced to R1.37/kWh, which brought the COE within 17% of the farm’s highest electricity tariff.

As a result of its simple design, financial performance and numerous other secondary benefits, the ‘Electricity only’ scenario was therefore considered likely to be viewed as a feasible investment from the perspective of the owners of Klein Constantia. The final decision, however, would rest upon the weight given to the secondary benefits, as the financial returns alone were considered insufficient to justify the investment. While some of these secondary benefits could be quantified, many others would be qualitative in nature and, as a result, would be subject to the views, interests and aspirations of the farm owners.

Chapter 6 – Conclusions and recommendations.

The primary goal of this study was to determine whether Klein Constantia wine farm would feasibly be able to substitute its current fossil-fuel derived energy needs with renewable energy generated from the farm's own resources. The study followed a progression from the literature survey, through to the site-analysis, design process and, finally, the proposed scenario designs.

It was shown that the farm would certainly be able to generate the required amount of energy, even with significant space and resource limitations in place. This was due primarily to the use of solar-PV, which contributed to more than half of the energy generation in all three scenarios. As a result of the Western Cape's favourable solar resources, PV clearly has an important role to play in the energy future of the wine industry. Its simple, modular design allows it to cater to a variety of energy demands, and, while this study focussed primarily on electricity generation, there would also be a number of other applications for stand-alone PV systems that could be considered at a later stage.

Of the five technology options, both micro-hydro and SWHs stood out as being particularly favourable. While micro-hydro presented the highest financial returns, SWHs scored well in the other design parameters and, as a result, were determined to be the more favourable of the two. Both technologies, however, were considered to be wise investments for the farm, and would likely remain so even if the non-financial benefits were removed from the equation.

Biomass presented a feasible option for energy generation, although it did not perform as well as some of the other technologies. Were the farm to expand its renewable energy targets sufficiently, however, biogas would certainly be a useful option to consider, and would bring numerous secondary benefits along with it. Small-wind, on the other, was not considered to be feasible in its current form, and would require a significant reduction in costs or a marked increase in the wind-resource estimate to make it viable.

In response to the primary objective, as determined at the beginning of the study, the final results appeared to be a mixture of both positive and negative factors. While it was shown to be potentially feasible to replace the farm's electricity and diesel usage without losing real value, the investment was considered to be risky. Furthermore, technological and cost issues stood in the way of actually achieving the goals as stated. While other options, such as biodiesel, could potentially assist in this endeavour; they would rely on significant changes to the practical limitations applied to renewable energy on the farm.

As a result of all of these factors, the 'Electricity only' scenario was considered to be the most feasible and realistic option available to the farm. Replacing the electricity usage would also produce the 'green credentials' and marketing leverage that the farm owners might desire from such a project. At the same time, the investment would be profitable and secure; and could easily be expanded to meet more ambitious energy targets in the future.

While this project did not deal with the South African wine industry's renewable-energy potential in a general sense, many of the findings from this case study could reasonably be applied to the greater industry. Due to the specific climatic conditions required to grow wine-grapes, technologies such as Biogas, SWHs and Solar PV, in particular, would likely be applicable to almost all wine-farms in the country. These three technologies alone accounted for more than three quarters of Klein Constantia's renewable energy potential. For this reason, it is considered likely that the general outlook for RE within the Western Cape wine region is positive and that much of the region's energy needs could feasibly be met through the use of renewable energy technologies.

Recommendations:

It is recommended that further studies be directed along the following lines:

- Further research should be conducted into the feasibility and operation of net metering within the Western Cape and South Africa.

As the viability of the proposed scenario rests so heavily on the use of net-metering, better clarity and understanding of the future of the technology within the Western Cape would be vital to the progress of the project.

- To determine which technologies best match the farm's varying power requirements and to asses the feasibility of load matching and energy storage as part of a RE-portfolio for the farm.

Were net-metering not assumed, load-matching and energy storage would invariably become vital to the feasibility of renewable-energy at Klein Constantia. As a result of this, were the farm to consider investing in renewable energy in the near future, it would be advised that they conduct significantly more research along these lines due to the current lack of appropriate legislation and infrastructure to support net-metering at present.

- Efficiency measures, that reduce the farm's overall energy demand, should be thoroughly investigated and implemented where appropriate.

During the various site visits to the farm, numerous opportunities for energy efficiency measures were noticed. These included opportunities within the winemaking process and others relating to the layout of the farm and the irrigation techniques in use. Were the farm to strongly consider investing in renewable technologies, they would be advised to first investigate these opportunities as they may be able to cost-effectively reduce the farms electricity demand and, in so doing, reduce the need for more costly renewable energy alternatives.

- Formal quotes should be acquired from the manufacturers, following a more comprehensive resource and site analysis, in order to better understand the budgetary requirements associated with each of the technologies.

- Further research should be directed towards determining the extent to which the findings of this study can be applied to the greater South African wine industry.

- A more comprehensive study should be conducted into the farm's diesel usage in order to determine the amount of renewable energy that would need to be generated to offset the diesel's carbon footprint.

- More accurate projections, relating to the future cost of electricity, labour and net-metering fees, should be incorporated into the financial analysis.

As this study assumed only inflationary increases in labour and electricity costs and no fees for net-metering, further research should be directed towards establishing more accurate predictions for these prices. This would lead to a more accurate and secure financial outlook for the proposed scenarios and would allow for better assessments of their feasibility.

- Further research should be conducted into legislative barriers that may effect the implementation of renewable energy at Klein Constantia.

As Klein Constantia is a historically significant site, the possibility of building or development restrictions was raised as a potential barrier to renewable energy investment on the farm. For this reason, were the farm to strongly consider investing in one of the proposed scenarios, they would need to thoroughly investigate the extent to which these restrictions would apply, and how they might affect the final portfolio design.

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